UNIT D

2.0

Global systems transfer energy through the biosphere.

Key Concepts

In this section, you will learn about the following key concepts:

- solar radiation budget
- climate zones, transfer of thermal energy by the hydrosphere and the atmosphere
- hydrologic cycle and phase change
- relationship between biomes and solar energy and climate

Learning Outcomes

When you have completed this section, you will be able to:

- identify the Sun as the source of all energy on Earth
- investigate and describe the relationships among solar energy reaching Earth's surface and time of year, angle of inclination, length of daylight, cloud cover, albedo effect, and aerosol or particulate distribution
- analyze the net radiation budget, using percent
- describe how thermal energy is transferred through the atmosphere and the hydrosphere, from latitudes of net radiation surplus to latitudes of net radiation deficit
- explain how thermal energy transfer through the atmosphere and hydrosphere affects climate
- describe and explain the greenhouse effect
- investigate and interpret how variations in thermal properties of materials can lead to uneven heating and cooling
- investigate and explain how evaporation, condensation, freezing, and melting transfer thermal energy
- describe a biome as an open system
- relate the characteristics of two biomes to net radiant energy, climatic factors, and topography
- analyze the climatographs of two major biomes, and explain why biomes with similar characteristics can exist in different geographical locations, latitudes, and altitudes

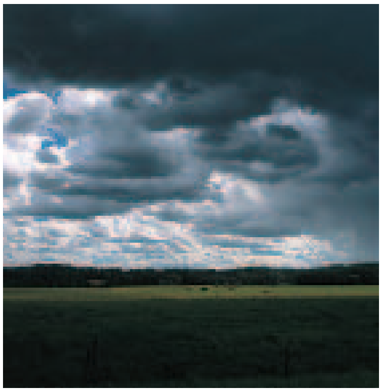


FIGURE D2.1 Life on Earth depends on the transfer of energy between the lithosphere, hydrosphere, and atmosphere.

Virtually all the energy on Earth initially comes from the Sun; that is, from **solar energy**. Life as we know it depends on this incoming solar energy. A small amount of the incoming solar energy is converted to food energy through photosynthesis, but most is converted to thermal energy. **Thermal energy** is the energy possessed by a substance by virtue of the kinetic energy of its molecules or atoms. A quantity of a substance at a high temperature has more thermal energy than the same quantity of that substance at a low temperature.

Different regions on Earth's surface have different amounts of thermal energy. In general, regions at or near the equator tend to be warmer, or have more thermal energy, than regions closer to the poles. What causes this general relationship and what consequences does it have for the biosphere?

Although the average temperature of Earth's surface generally decreases as one moves away from the equator, there are many exceptions. For example, consider the following cities in Canada: Vancouver, BC, Lethbridge, AB, and Gander, NF. According to Environment Canada, between 1971 and 2000, Vancouver had an average annual temperature of 10.1°C. During the same period, the average annual temperature in Lethbridge was 5.7°C, and 3.8°C in Gander. What factors contribute to these variations in climate?

In this section, you will learn about factors that affect the amount of solar energy that reaches our planet's surface. You will explore how differences in Earth's atmosphere, lithosphere, and hydrosphere can affect the absorption of solar energy and its conversion to thermal energy. You will also discover how thermal energy is transferred between regions of Earth by the atmosphere and the hydrosphere. You will use this knowledge to analyze the climates of different regions on Earth called biomes, and then explain why biomes with similar characteristics can exist in different locations on Earth.

D 2.1 Energy Relationships and the Biosphere

Solar energy is **radiant energy**, or energy that is transmitted as electromagnetic waves. Solar energy consists of electromagnetic waves at different wavelengths, which together make up the electromagnetic spectrum (Figure D2.2). The electromagnetic spectrum can be divided into classes of waves that fall within a certain wavelength range. The radiation at wavelengths in the range that we can see is called visible light. The amount of energy carried per wavelength also varies across the spectrum. For example, waves of radiation in the gamma ray range will carry far more energy than an equal number of waves in the radio wave range.

Although virtually all the energy on Earth comes from the Sun, all regions do not receive the same amount of solar energy. **Insolation** is the amount of solar energy received by a region of Earth's surface. Insolation depends on latitude, and on specific characteristics of the lithosphere, atmosphere, and hydrosphere in a region, some of which can change from day to day.

info **BIT**

The Sun provides 100 000 times more energy than all the sources of energy on Earth combined, including naturally occurring sources and transformation technologies from human-made sources.

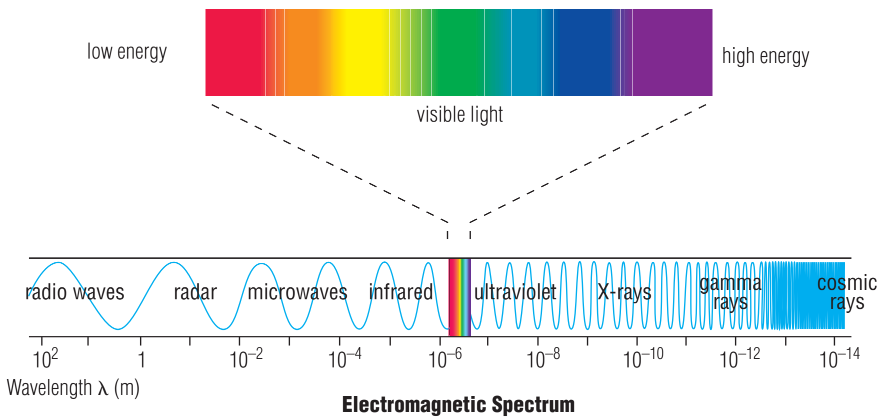


FIGURE D2.2 The electromagnetic spectrum contains many different types of radiation, which are distinguished from one another by their wavelengths. Solar energy is composed of all the types of radiation in the electromagnetic spectrum.

Insolation and the Angle of Inclination

If you were to line up Earth's poles relative to the plane of its orbit around the Sun, you would find that the poles would be slightly tilted, rather than perpendicular (straight up and down) to the orbital plane. The **angle of inclination** refers to the degree by which Earth's poles are tilted from the perpendicular of the plane of its orbit. Earth has an angle of inclination of 23.5° (Figure D2.3).

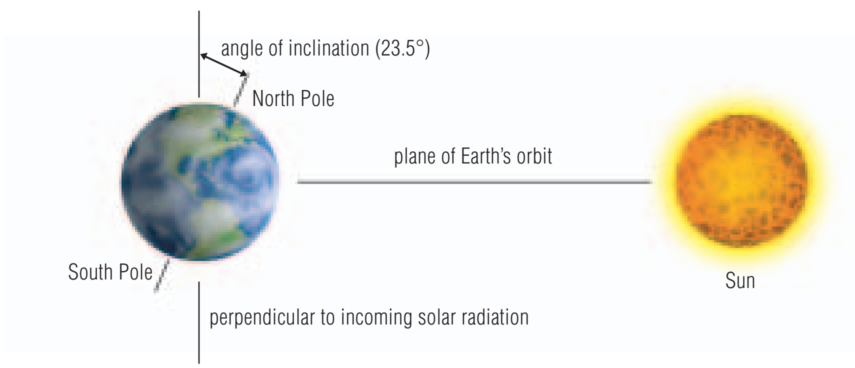


FIGURE D2.3 The tilt of Earth's axis is 23.5° from the perpendicular of the plane of its orbit.

Earth orbits the Sun once per year. On the first day of summer in the Northern Hemisphere (June 21), the angle of inclination causes the North Pole to be tilted toward the Sun (Figure D2.4). On the first day of winter in the Northern Hemisphere (December 21), however, the North Pole is tilted away from the Sun. The North Pole therefore receives more insolation during our summer, whereas the South Pole receives more insolation during our winter. Regions in the Northern Hemisphere, such as Canada, therefore have warmer temperatures from about March to September, whereas regions in the Southern Hemisphere, such as Australia, have warmer temperatures from September to March.

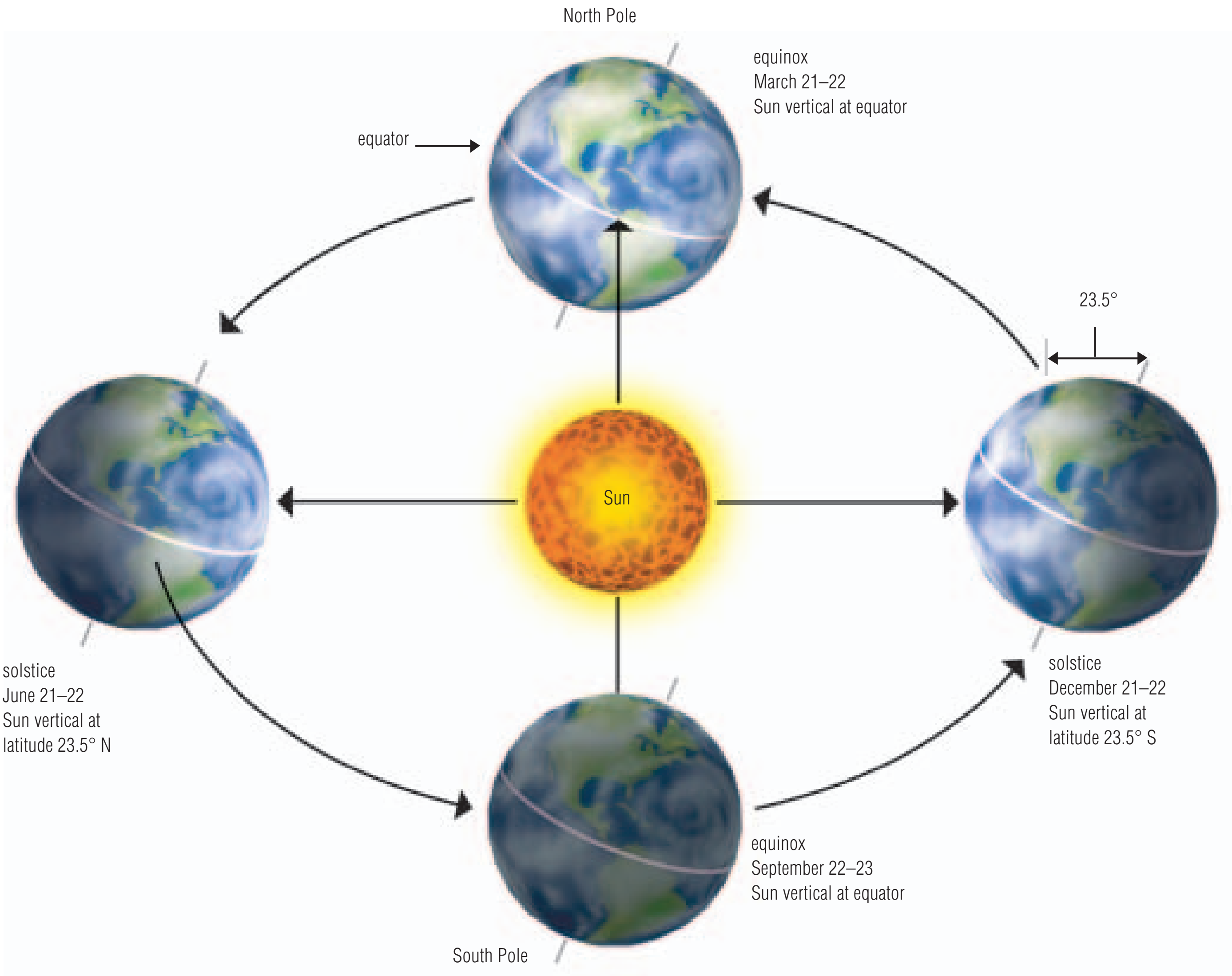


FIGURE D2.4 Earth's angle of inclination causes the seasonal change in insolation at more polar latitudes. The dates of the equinoxes and solstices may vary by one day, depending on whether a particular year is a leap year.

Earth can be divided into different **latitudes**, which are imaginary lines that run parallel to the equator. The equator is at latitude 0°, and the poles are at latitudes 90° N and 90° S. The remainder of Earth's surface is divided equally with parallel lines between these points. The angle of inclination also causes variation in the number of hours of daylight at different latitudes. At more northern latitudes, such as in Canada, there are more hours of daylight as the North Pole becomes tilted toward the Sun. A **solstice** is one of two points in Earth's orbit at which the poles are the most tilted toward or away from the Sun. The solstice that occurs on June 21–22 is the day that has the most hours of daylight in northern latitudes, but the least hours of daylight in the southern latitudes. Regions of Earth at or near the equator experience little variation in the number of hours of daylight. An **equinox** is one of two points in Earth's orbit when the number of daylight hours is equal to the number of hours of night.

Insolation and the Angle of Incidence

The shape of Earth also affects the insolation of regions at different latitudes. Earth is roughly spherical. As a result, most incoming solar radiation is not perpendicular to Earth's surface. The **angle of incidence** is the angle between a ray falling on a surface and the line of the perpendicular to that surface. At the equator, the angle of incidence of incoming solar radiation is 0°. As you move from the equator to the poles, the angle of incidence of the Sun's rays increases. At larger angles of incidence, the same amount of radiation is spread out over a greater surface area (Figure D2.5). Therefore, areas at more polar latitudes always receive less solar energy per square kilometre than areas at or near the equator.

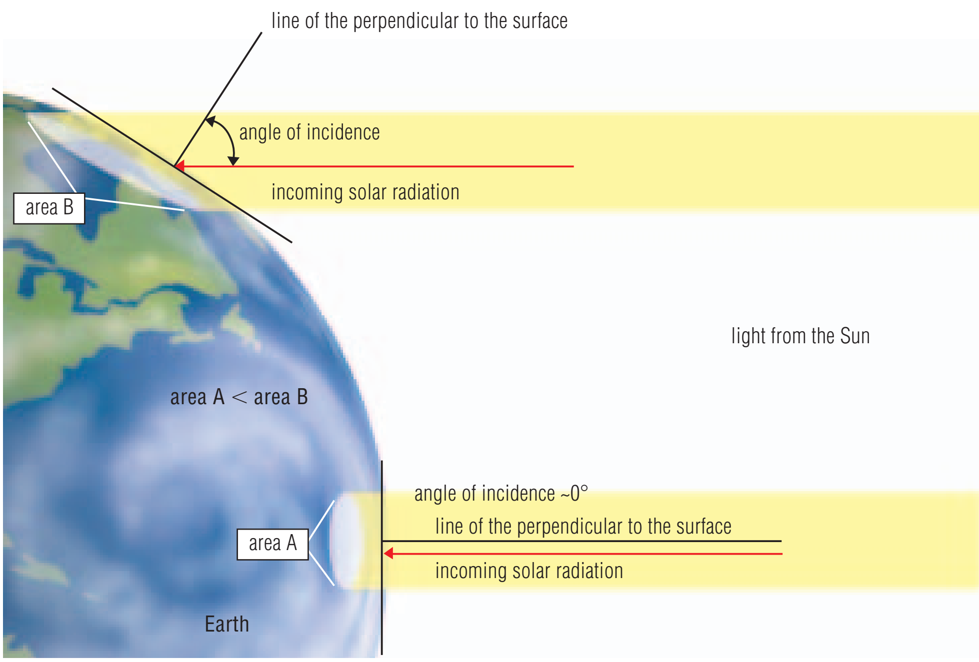


FIGURE D2.5 The angle of incidence increases with distance from the equator. As a result, the same amount of solar energy is spread over a larger surface area at more polar latitudes, such as area B, than at or near the equator, such as area A.

Activity D5

Inquiry Lab

Student Reference 2

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Angle of Incidence and Rate of Temperature Change

CAUTION: To avoid a burn injury, be careful not to touch the light bulb.

The Question

How does the angle of incidence of radiant energy affect the rate of temperature change along a surface?

The Hypothesis

Create a hypothesis that answers the question.

Variables

Which is the manipulated variable in this experiment: the angle of incidence or the rate of temperature change?

Materials and Equipment

thermometer or temperature probe
100-W lamp
black construction paper
protractor
books or blocks

Procedure

1. Cut a 5 cm by 10 cm strip of black construction paper. Fold the paper, and tape the two sides to form a pocket, as shown in Figure D2.6.

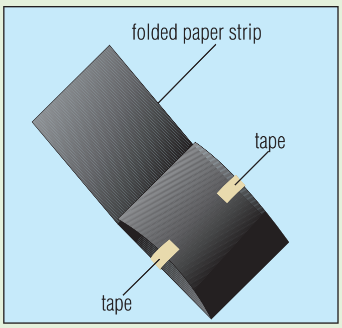


FIGURE D2.6 Fold your paper strips to form a pocket.

2. You will be directing radiant energy from a lamp onto the pocket, at angles of incidence of 0°, 45°, and 90°. Create a data table that will allow you to record the temperature inside the pocket every minute for 15 min, for each of these angles.
3. Place the pocket on books or blocks so that it is level with the lamp bulb, and at a distance of 30 cm (Figure D2.7). Using another book or block to support the pocket, position the pocket so the rays from the lamp hit the pocket at an angle of incidence of 0°.

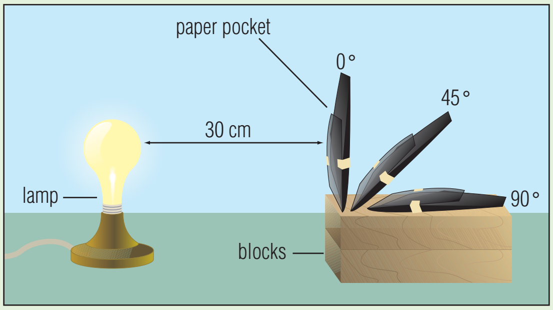


FIGURE D2.7 The experimental set-up

4. Place the thermometer or temperature probe inside the pocket, ensuring that the black paper surrounds the bulb or probe end.
5. Record the initial temperature inside the pocket.
6. Turn on the lamp. Measure and record the temperature inside the pocket every minute for 15 min.
7. Repeat steps 4 to 6 with the angle of incidence at 45° and then 90°, as shown in Figure D2.7.
8. Switch off the lamp when you have completed your investigation.

Analyzing and Interpreting

1. Identify the manipulated variable and the responding variable in this experiment.
2. Identify all the variables that were held constant during the investigation. Why was it important to keep these variables constant?
3. Create a line graph of your data. Use solid, dashed, and dotted lines, or lines of different colours to plot the results for each of the angles of incidence.

Forming Conclusions

4. Describe how the angle of incidence affected the rate of temperature change.
5. Identify the angle of incidence that exposed the pocket to the most radiant energy. Which angle exposed the pocket to the least radiant energy? Describe the evidence you used to come to your conclusion.

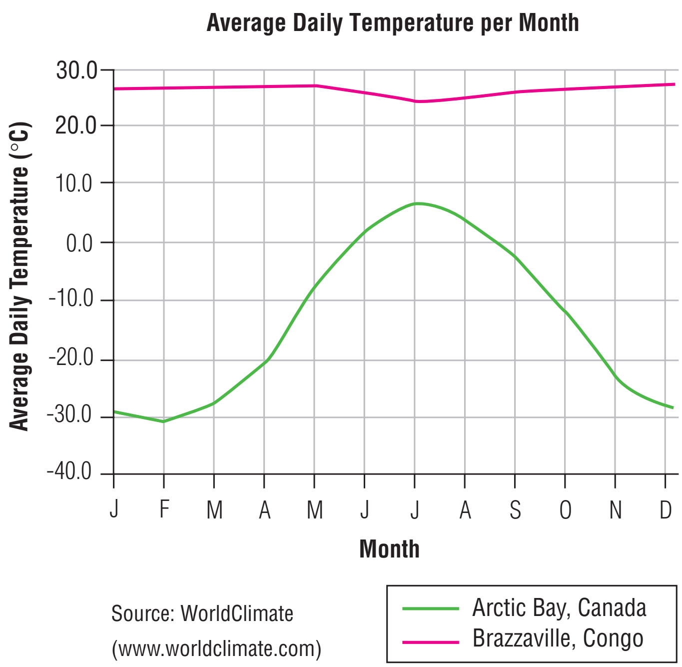
Applying and Connecting

6. Consider your experiment as a model of Earth. Describe the consequences of the angle of solar radiation incidence on average temperature at different latitudes on Earth, using your data to illustrate your answer.

Extending

7. In this experiment, the black paper absorbs most of the radiant energy from the lamp. Design an experiment that would allow you to test whether the rate of temperature change of a substance that reflected more radiant energy (such as another colour of paper) was affected by the angle of incidence in a similar way as was the black paper. Include a hypothesis in your experimental design.

The Earth's shape and the angle of incidence play a large role in creating Earth's climate. From the equator to the pole, there is a progressive decrease in insolation year-round. As a result, the average annual air temperature is highest at the equator, and decreases as you move toward the poles. There is little variation in the number of hours of daylight with the seasons at the equator, but the number of hours of daylight varies progressively with the seasons at increasingly higher and lower latitudes. There is therefore more variation in average daily temperature throughout the year as you move closer to the poles (Figure D2.8).



Source: WorldClimate (www.worldclimate.com)

FIGURE D2.8 This graph shows the variation in average daily temperature per month for Arctic Bay, Nunavut, which is at latitude 73.00° N, and Brazzaville, Congo, at latitude 4.25° S. The data for Arctic Bay are the averages of temperatures recorded from 1937 to 1976. Data for Brazzaville were recorded from 1941 to 1972.

Absorption and Reflection by the Biosphere

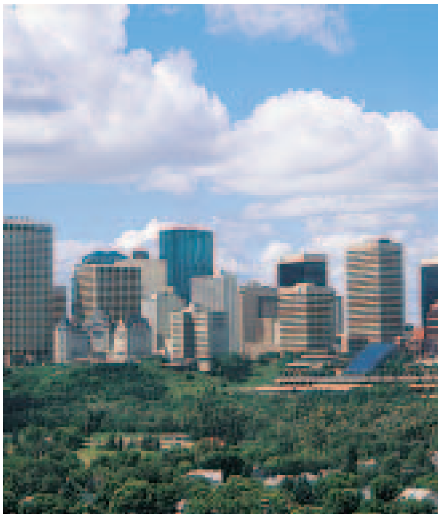


FIGURE D2.9 Clouds reflect some of the incoming radiation, but also absorb energy from Earth's surface.

As soon as the radiation from the Sun reaches Earth's outer atmosphere, it may be reflected or absorbed by particles of matter. When particles **reflect** energy, they simply change the ray's direction. When particles **absorb** energy, the energy is converted into another form of energy, such as kinetic energy of the particles. When a substance absorbs energy, the temperature of that substance will increase.

Absorption and reflection of solar radiation occurs in all three components of the biosphere. The reflected radiation either goes back into space, or is absorbed elsewhere in the biosphere. Some of the absorbed solar energy is re-emitted as thermal energy, which warms the atmosphere, lithosphere, and hydrosphere. Some of the kinetic energy resulting from energy absorption is used to drive the movement of water through the hydrologic cycle, and the movement of air as wind. A small amount of the solar energy is converted to chemical energy by the process of photosynthesis, and is then passed on to other organisms through food webs.

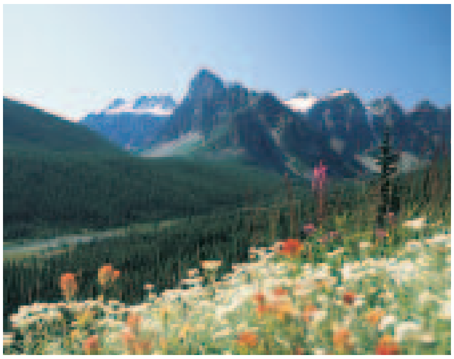
The layers of the atmosphere (troposphere, stratosphere, mesosphere, and thermosphere) contain different mixtures of gases. These different gas mixtures absorb or reflect the energy from different areas of the electromagnetic spectrum. High-energy radiation, such as X-rays and gamma rays, are absorbed by oxygen and nitrogen gases, mostly in the mesosphere, thermosphere, and stratosphere. Ozone absorbs most of the ultraviolet radiation. Carbon dioxide and water vapour in the atmosphere absorb infrared radiation, as do other gases such as methane. Visible light and radio waves make it to Earth's surface with very little absorption by the atmosphere.

Cloud Cover and Atmospheric Dust

FIGURE D2.10 Large amounts of atmospheric dust affect the amount of radiation that reaches Earth's surface.

Most clouds and atmospheric dust (particles less than 0.66 mm in diameter) are found in the troposphere. The amount of cloud cover and atmospheric dust over any region varies daily, but some regions will commonly have cloudy skies, and some regions usually have relatively high levels of atmospheric dust. Human activity has also caused an overall increase in the amount of atmospheric dust in some regions, especially those over industrialized nations.

Clouds reflect some incoming solar radiation back into space. As a result, the air temperature is cooler on a cloudy day (Figure D2.9). However, clouds also absorb energy that is emitted by Earth's surface, which helps to warm the planet. Atmospheric dust behaves in a similar way. It can shade Earth's surface from incoming radiation, reducing the amount of solar energy that reaches the lithosphere and hydrosphere. Atmospheric dust also absorbs some of the incoming energy from the Sun and some of the thermal energy emitted by Earth's surface. When a natural or human-made event, such as a volcanic eruption or a large forest fire, expels large volumes of dust into the atmosphere, the effect on climate can be significant. Such effects can be very difficult to predict (Figure D2.10).



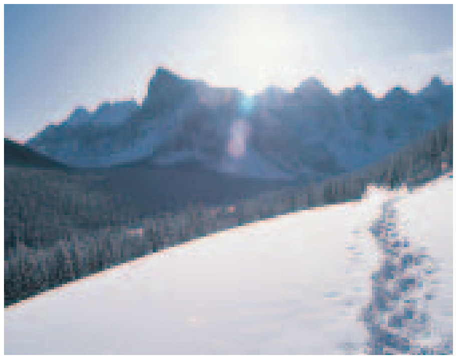


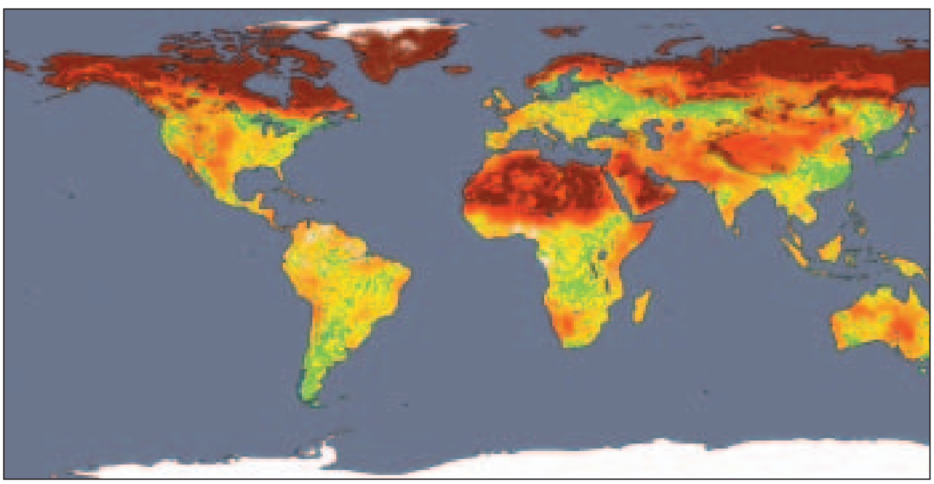
FIGURE D2.11 The albedo of an area can vary with the seasons. This variation affects the amount of solar energy that reaches Earth's surface at that locale.

Albedo—Reflection by the Lithosphere and Hydrosphere

The solar radiation that reaches Earth's surface is either reflected or absorbed. The amount of solar energy that is reflected versus the amount absorbed depends on the type of surface encountered by the incoming radiation. Scientists have invented a scale to measure the reflectivity of a surface, called the albedo. The **albedo** of a surface is the percent of solar radiation that it reflects. Light-coloured, shiny surfaces, such as snow, reflect more solar energy than darker, duller surfaces such as forests or soils.

The average albedo for Earth's surface is 30%, or 0.30. Each region of Earth has a different albedo value, depending on its surface features. For example, the albedo of the polar icecaps is much higher than the albedo of the forests of northern Alberta, or of the deserts of Africa. Albedo can also vary with the seasons. Most areas in Canada have a higher albedo in the winter than in the summer (Figure D2.11), due to the change in the amount of snow cover.

Figure D2.12 shows the albedo of Earth's surface according to data collected from April 7–22, 2002, by certain NASA satellites. In this image, regions with the highest albedo are red. The snow and ice cover of northern latitudes causes these regions to have a high albedo year-round. Areas that lack forest cover, such as the Sahara desert of Africa, also have a high albedo. Yellows and greens show regions with intermediate albedo values, and regions with low albedo are coloured blue or violet. No data were available for regions that are white, or for oceans.



Source: NASA

FIGURE D2.12 The average albedo of Earth's surface from April 7 to 22, 2002. Polar regions with high amounts of snow have a high albedo. Cloud cover, atmospheric dust, and forest cover also affect the albedo of an area.

Activity D6

Inquiry Lab

Student Reference 7

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Modelling Albedo in the Biosphere

CAUTION: To avoid burn injury, do not touch the light bulb.

The Question

When two samples with differing albedo, white and green sugar, are exposed to equal amounts of radiation, will the amount of temperature change above and below the surface of the samples differ?

The Hypothesis

Create a hypothesis that relates the albedo of white sugar and green sugar to the change in temperature above and below the surface of the sugar samples.

Variables

Identify the responding and manipulated variables, and the variables that must be controlled in this experiment.

Materials and Equipment

3 paper baking cups
3 thermometers or temperature probes
reflector lamp with a 200-W bulb
white sugar
green-dyed sugar
timer
graph paper, spreadsheet software, or graphing calculator

Procedure

1. Fill one baking cup with white sugar, and a second baking cup with green sugar. Both baking cups should be filled as close to the top as possible, and the surface of the sugar should be flat. Leave the third baking cup empty. This will be your control.
2. You will be measuring the temperature of the air just above the sugar samples and just below the surface of the sugar samples every 2 min for 10 min. You will also be measuring the temperature of the air in the control at these same times. Using paper or spreadsheet software, create a data table that will allow you to record these data. If you are using a graphing calculator, open the appropriate application to collect or enter temperature data.
3. Place the lamp so that it is about 30 cm above the containers.
4. Place the bulb of one thermometer or one temperature probe just under the surface of each sugar sample. Place the third thermometer or temperature probe inside the empty baking cup so that it is not touching any surface. Record the initial temperature of each.
5. Using the same thermometers or temperature probes, measure and record the temperature of the air just above the surface of each sugar sample.
6. Turn on the lamp and start the timer. Repeat the temperature measurements in steps 4 and 5 every 2 min for 10 min with the light on. After 10 min, carefully turn off the lamp.

Analyzing and Interpreting

1. Using the data in your table, create a graph of the temperature versus time. Your graph should include temperatures above and below each sugar sample and in the control, for each time point.

2. Using your graph, describe the changes that occurred in the temperature above and below the surface of the white sugar and the green sugar, and in the control. Outline any differences among the two samples and the control.

3. According to your graph, over which sugar sample did the air temperature change more when the light was on? Relate this to the albedo of the two sugar samples.

4. According to your graph, which sugar sample absorbed more radiation when the light was on? Relate this to the albedo of the two sugar samples.

5. Why did you need to determine the temperature of the air in the empty baking cup?

Forming Conclusions

6. Review your hypothesis. Write a paragraph that explains whether your data and analysis support or refute your hypothesis.

Applying and Connecting

7. Imagine you are in a park in the summer. The Sun is shining on a grassy area and on the sand beach. Will the air just above the sand or just above the grass be warmer? Why?

8. The far north of Canada is mainly covered with ice and snow year-round, whereas the more southern regions are covered with snow only during the winter. Would the northern or the southern regions of Canada absorb more solar radiation? Explain your answer by referring to the results of this experiment.

Extending

9. Using green and white sugar, design an experiment that would model how albedo varies between the summer and winter months in your area. When your teacher approves your experimental design, conduct your investigation.

Natural Greenhouse Effect

Some of the radiant energy that is absorbed by Earth's surface is re-emitted into the atmosphere as infrared radiation, which has high thermal energy (Figure D2.13). This re-emitted thermal energy helps to keep the temperature of our planet in the range that supports life.

Most of the thermal energy is absorbed in the atmosphere by clouds, water vapour, and gases such as carbon dioxide and methane. Without the atmosphere, this thermal energy would escape into space, and Earth would be significantly cooler. The absorption of thermal energy by the atmosphere is known as the **natural greenhouse effect**. Without the natural greenhouse effect, the average temperature on Earth would be about 33°C lower.

Greenhouse gases are gases that contribute to the greenhouse effect. Since it is present in such high amounts in the atmosphere, the main contributor to the natural greenhouse effect is water vapour. However, carbon dioxide and other gases, methane and nitrous oxide (N_2O, also called dinitrogen monoxide), also absorb significant amounts of thermal energy.

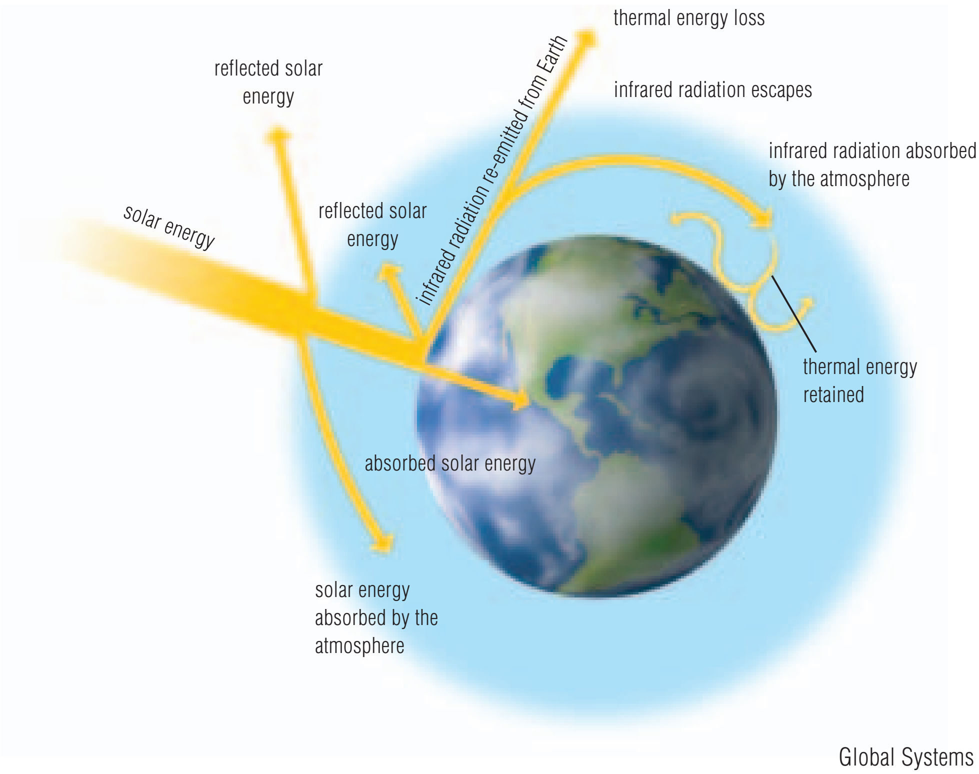


FIGURE D2.13 The natural greenhouse effect keeps Earth warm enough to support life by absorbing some of the infrared radiation re-emitted from Earth's surface.

Activity D7

Inquiry Lab

Student Reference 2

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

The Greenhouse Effect

CAUTION: To avoid burn injury, do not touch the lamp.

The Question

How does the greenhouse effect help to maintain temperature?

The Hypothesis

The greenhouse effect results in more absorption of thermal energy, and reduces the amount of thermal energy that radiates back into space.

Variables

In this experiment, you will be measuring the temperature change inside and outside a model greenhouse over time. Identify the manipulated, responding, and all controlled variables.

Materials and Equipment

2-L clear plastic bottle

tape

one-hole stopper to fit bottle

2 thermometers or temperature probes

reflector lamp with 200-W bulb

retort stand

clamp

graph paper, spreadsheet software, or graphing calculator

Procedure

1. Carefully insert one of the thermometers or temperature probes into the one-hole stopper. Fit the stopper assembly snugly into the top of the 2-L bottle. The bulb should be as far down into the bottle as possible.
2. Secure the thermometer or temperature probe in place with tape.
3. With the clamp, attach the second thermometer to the retort stand so that its bulb is at about the same height as the one inside of the bottle. Position the stand and thermometer near the bottle.
4. Position the heat lamp so it is at an equal distance from both thermometers. Your model should look like Figure D2.14.

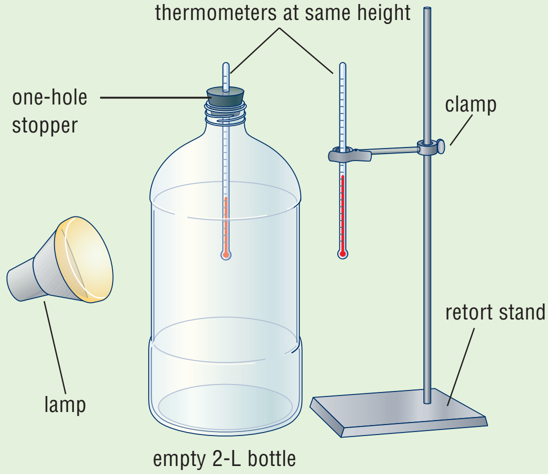


FIGURE D2.14 The completed model

5. Create a data table that will allow you to record the temperature change inside and outside of the bottle every minute for approximately 15 min.
6. Turn on the lamp. Record the initial temperature, then the temperature at 1 min intervals. When the temperature stops rising, continue to record the temperature for another 3 to 5 min.

Analyzing and Interpreting

1. Graph your results. Plot the time in minutes on the horizontal axis and the temperature in °C on the vertical axis. Use solid and dashed lines to distinguish the temperature inside the bottle from the temperature outside the bottle. Include a legend.
2. Compare the temperature changes that occurred inside the bottle to those outside. Explain any differences you observed.

Forming Conclusions

3. Explain why the temperature eventually stopped rising inside the bottle, referring to the energy coming in and going out.
4. Was the bottle a good model of the natural greenhouse effect of the atmosphere? Identify the limits of the model in your answer.

Extending

5. Describe how you could use the albedo of different substances to generate a higher temperature in the bottle than recorded in this activity.

Net Radiation Budget

Earth is a warm, habitable planet because incoming solar radiation is absorbed by Earth's surface and the atmosphere. However, not all the incoming solar energy is absorbed. Some is reflected out to space, and some is re-emitted as thermal energy by Earth's surface and atmosphere. The **net radiation budget** is the difference between the amount of incoming radiation and of outgoing radiation re-emitted from Earth's surface and atmosphere. Incoming radiation is all the solar energy that reaches Earth's surface, not including the solar radiation that is reflected by the atmosphere and by the albedo of Earth's surface. Outgoing radiation is the thermal radiation re-emitted by Earth's surface and atmosphere that is not absorbed by the greenhouse gases of the atmosphere. The net radiation budget of Earth can be written as a word equation:

net radiation budget = incoming radiation – outgoing radiation

Activity D8

QuickLab

Earth's Net Radiation Budget

Purpose

To analyze Earth's net radiation budget

Materials and Equipment

graph paper, graphing calculator, or spreadsheet software

Procedure

1. Using the information in Figure D2.15, create a pie chart that illustrates what happens to incoming radiation. Use different colours to represent reflected solar energy, absorbed solar energy, and re-emitted solar energy.

Questions

1. What is the total amount of solar energy reflected back into space, in percent?
2. What percent of solar energy is re-emitted from Earth back into space?
3. What is the total amount of solar energy absorbed by Earth, in percent?
4. Describe what happens to the solar energy coming to Earth. Your description should include the following terms: solar energy, energy input, and energy output.

FIGURE D2.15 For Earth as a whole, the net radiation budget is in balance. In other words, the amount of radiation coming in to Earth is the same as the amount that goes back into space.

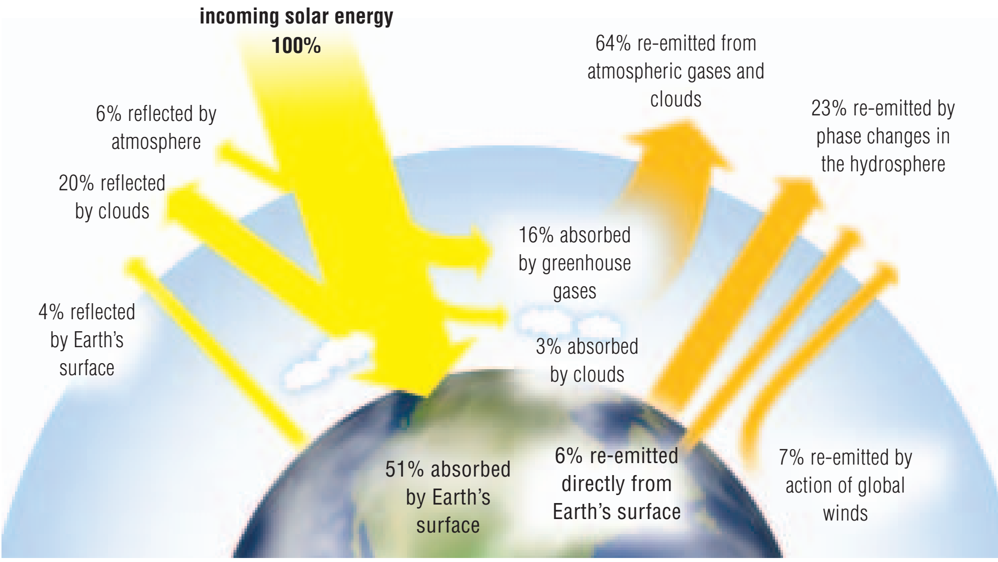


Figure D2.15 shows the relative contribution of different aspects of Earth's average net radiation budget, based on data collected by NASA for the Earth Radiation Budget Experiment project. When solar energy reaches Earth, some of the radiation is immediately reflected back out to space by the atmosphere (6%), clouds (20%), and Earth's surface (4%). The remaining incoming radiation is absorbed directly by greenhouse gases in the atmosphere (16%), clouds (3%), and the Earth's surface (land and water: 51%). On average, all the energy absorbed by the atmosphere, lithosphere, and hydrosphere is eventually emitted and radiated back into space as thermal energy. Absorbed solar energy is radiated from clouds and atmospheric gases (64%), by phase changes in the hydrosphere (23%), by the action of global winds (7%), and directly from Earth's surface (6%). You will learn more about some of these events later in this unit.

On average, the amount of incoming radiation is equal to the outgoing radiation for all of planet Earth. In other words, incoming radiation minus outgoing radiation equals zero. If this balance were to change, then the average global temperature would either increase or decrease, until the net radiation budget was balanced again. For example, if the amount of radiation re-emitted back into space were to decrease and the amount of incoming radiation remained the same, Earth's average global temperature would increase.

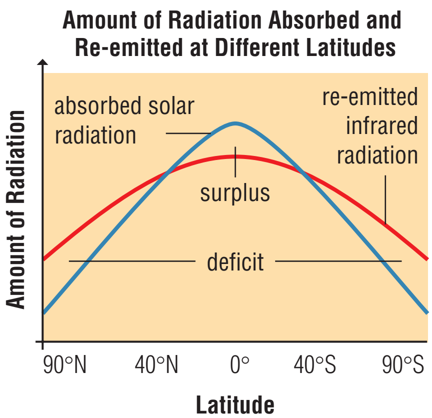


FIGURE D2.16 Average distribution of absorbed and re-emitted radiation on Earth

Net Radiation Budget and Latitude

Although the net radiation budget is balanced for Earth as a whole, some regions on Earth have an unbalanced net radiation budget. Latitude is an important factor in predicting whether the net radiation budget of a region will be out of balance. For example, polar regions tend to always have lower insolation and higher albedo than other regions on Earth. As a result, at polar latitudes (90° S or 90° N), there tends to be less incoming radiation than outgoing radiation (Figure D2.16).

The poles therefore always have a net radiation budget deficit. Regions near the equator (latitude 0°) tend to have higher insolation, which results in more incoming radiation relative to outgoing radiation. Regions on and near the equator always have a net radiation budget surplus.

If the only factor that determined climate were differences in net radiation budget, then the average temperature in regions with a net radiation budget surplus, such as at the equator, would be expected to increase over time, since the excess radiation would be converted to thermal energy. Similarly, in regions with a net radiation budget deficit, such as at the poles, the average temperature would be expected to decrease over time, since the amount of emitted thermal energy would be greater than the amount of absorbed radiation. These trends do not occur, however. In the following sections, you will find out how thermal energy is transferred from latitudes with a net radiation surplus to latitudes with a net radiation deficit.

reSEARCH

The Earth Radiation Budget Experiment (ERBE) was started in 1984. Find out how this project monitors Earth's radiation budget, and how the information is used. Begin your search at www.pearsoned.ca/school/science10

D2.1 Check and Reflect

Knowledge

1. Describe how the amount of solar energy reaching the poles varies during the year.
2. How does cloud cover influence the amount of solar radiation that reaches Earth's surface?
3. What determines the albedo of a material?
4. What is the electromagnetic spectrum?
5. Describe the source(s) of energy that reach the troposphere.
6. Explain what is meant by the term "Earth's net radiation budget."
7. When does the North Pole receive the highest insolation? What is happening to the insolation at the South Pole at this time?
8. Compare the albedo of an area that is covered in snow to an area covered with dark soil.
9. Describe what happens to the solar energy that is absorbed by Earth's surface.
10. Distinguish between the angle of inclination and the angle of incidence.
11. What happens to the solar energy that reaches Earth's surface, but is not reflected back into space?
12. Identify the factors that affect the amount of radiation that reaches a region of Earth's surface.
13. Outline the effect of the angle of inclination on the amount of solar energy that reaches Earth.

Applications

14. The city of Ynnus is located on the equator, and Ywons is at the North Pole. In a table, compare the relative number of hours of daylight and amount of insolation that would be received by these two cities on December 21 and on March 21 of any year.
15. Using an illustration in your answer, explain the natural greenhouse effect.
16. Two cities located in the desert have the same altitude and latitude, but have different surface features. The city of Rocky Peaks is surrounded by a dark rocky surface. The city of Sandy Beach is surrounded by light-coloured sand. Neither city ever has snow. Which city will have the higher average temperature in the summer? Which will have the higher average temperature in the winter? Explain your answers.

Extensions

17. Create an illustration to show as many factors as possible that would likely affect the amount of solar radiation that reaches Earth's surface in your area.
18. The amount of solar energy reflected by water at midday is 5% to 10%. Explain why this percent would vary during the day.

D 2.2 Thermal Energy Transfer in the Atmosphere

info BIT

A resting person transfers about 100 J of thermal energy every second into the atmosphere. This is the same amount of energy emitted per second by a 100-watt light bulb.

Thermal energy transfer is the movement of thermal energy from an area of high temperature to an area of low temperature. Suppose you brought a bicycle outdoors on a cold day. The temperature of the bicycle would fall to the same temperature as the air outside. If you were then to bring the bicycle back inside, the temperature of the bicycle would increase to the indoor temperature. In this example, thermal energy first was transferred from the bicycle to the air, and then from the air to the bicycle. Thermal energy transfer can occur by conduction or convection.

Conduction and Convection

Radiation is the emission of energy as particles or waves. When radiant energy encounters particles of matter, it may be reflected or absorbed. Absorbed energy can increase the movement of the particles (their kinetic energy). An increase in kinetic energy increases the temperature of the matter. Any substance at a higher temperature than its surroundings will emit radiant energy, usually as infrared radiation. For example, the Sun radiates energy in the form of electromagnetic waves (solar energy), some of which travels to Earth. When this radiant energy reaches Earth's atmosphere, some of it is absorbed by particles of matter, such as molecules of carbon dioxide gas. The absorbed radiant energy increases the kinetic energy of the carbon dioxide molecules, and the temperature of the carbon dioxide gas increases. The warmed carbon dioxide gas may then transfer some of its thermal energy to substances at lower temperatures, or re-emit it as infrared radiation.

Conduction is the transfer of thermal energy through direct contact between the particles of a substance, without moving the particles to a new location. Thermal energy transfer by conduction usually takes place in solids. Recall that particles in a solid all have a certain average kinetic energy. During conduction, particles with more kinetic energy transfer some of their energy to neighbouring particles with lower kinetic energy. This increases the kinetic energy of the neighbouring particles, which may in turn transfer energy to other neighbouring particles, increasing their kinetic energy. For example, in Figure D2.17, the burner is radiating energy to the solid metal pan. The particles of metal closest to the burner absorb some of this radiated energy and increase in kinetic energy. These particles can then transfer energy to neighbouring particles, causing an increase in temperature.

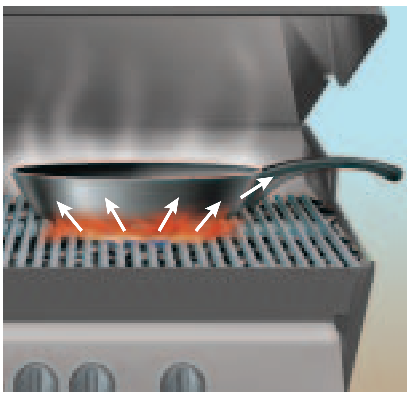


FIGURE D2.17 In this illustration, energy is radiated from the heating element and is absorbed by the lower surface of the pan. The absorbed radiant energy increases the kinetic energy of the particles in this part of the pan. Thermal energy is then transferred to other parts of the pan by conduction. Conduction transfers thermal energy from one particle to another through direct contact.

Convection is transfer of thermal energy through the movement of particles from one location to another. Thermal energy transfer by convection usually occurs in **fluids**, which are substances with no definite shape (such as gases and liquids). During convection, the movement of the particles forms a **current**, or a flow from one place to another in one direction. For example, when the water in the pot in Figure D2.18 absorbs energy from the burner, the water molecules increase in kinetic energy. The water molecules then begin to move apart from one another, causing the water to expand in volume. This expansion lowers the **density**, or mass per volume, of the water. The less dense water will rise to the top, forming an upward convection current. When it contacts the cooler air at the surface, the water will cool and contract, which increases its density and forms a downward convection current (Figure D2.18).

FIGURE D2.18 Convection transfers thermal energy through the movement of particles from one location to another.

Activity D9

QuickLab

Convection

CAUTION: To avoid being scalded, do not touch the apparatus.

Materials and Equipment

paper and pen

watch or clock

assembled apparatus as shown

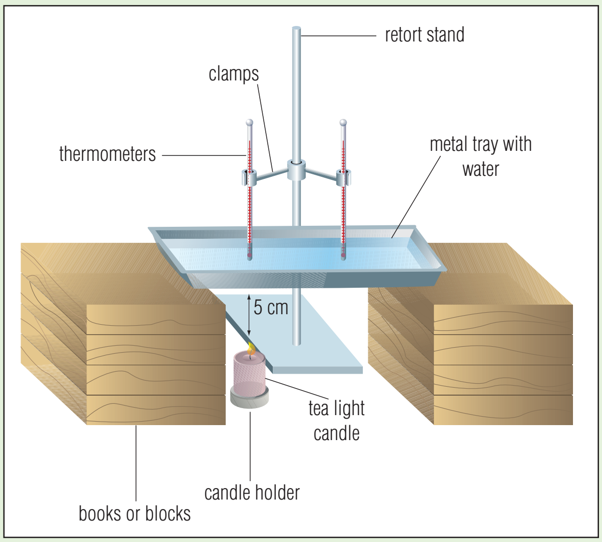


FIGURE D2.19 The candle is placed directly under the pan.

Procedure

1. On a clean sheet of paper, create a table that will allow you to record the two temperature readings from each thermometer. You will use the rest of the sheet to record your observations.
2. Your teacher will measure the initial temperature of the water with both thermometers. Record these measurements.
3. Your teacher will now add one drop of food colouring below each thermometer. Observe and record the movement of the food colouring.
4. You teacher will light the tea light and place it at the centre of one end of the pan. Observe and record what happens to the food colouring over the next 10 min.
5. After 10 min, your teacher will measure the final temperature of the water with both thermometers. Record these measurements.

Questions

1. In a table, compare and contrast the movement of the food colouring before and after the water was heated.

2. Write a paragraph to summarize your observations. In a second paragraph, discuss how this activity illustrated thermal energy transfer in the atmosphere.

3. If an open bottle of perfume were heated, would the effect be similar to the results of this activity? Explain your reasoning.

Effects of Thermal Energy Transfer in the Atmosphere

The temperature of the atmosphere tends to increase in areas close to or on the equator. As the heated atmospheric gases gain energy and expand, the air becomes less dense and rises. In areas close to or at the poles, the temperature of the atmosphere tends to decrease. Here, the cooling atmospheric gases lose energy and contract, and the air becomes denser and falls. If the Earth were not spinning, there would be a continuous convection current between the polar and the equatorial regions (Figure D2.20).

Atmospheric pressure is the pressure exerted by the mass of air above any point on Earth's surface. Since warm air is less dense than cold air, warmer regions of the atmosphere exert less atmospheric pressure than cooler regions. **Wind** is the movement of cool air from these areas of high pressure to areas of low pressure. The rising and sinking masses of air in convection currents cause changes in atmospheric pressure, which cause wind.

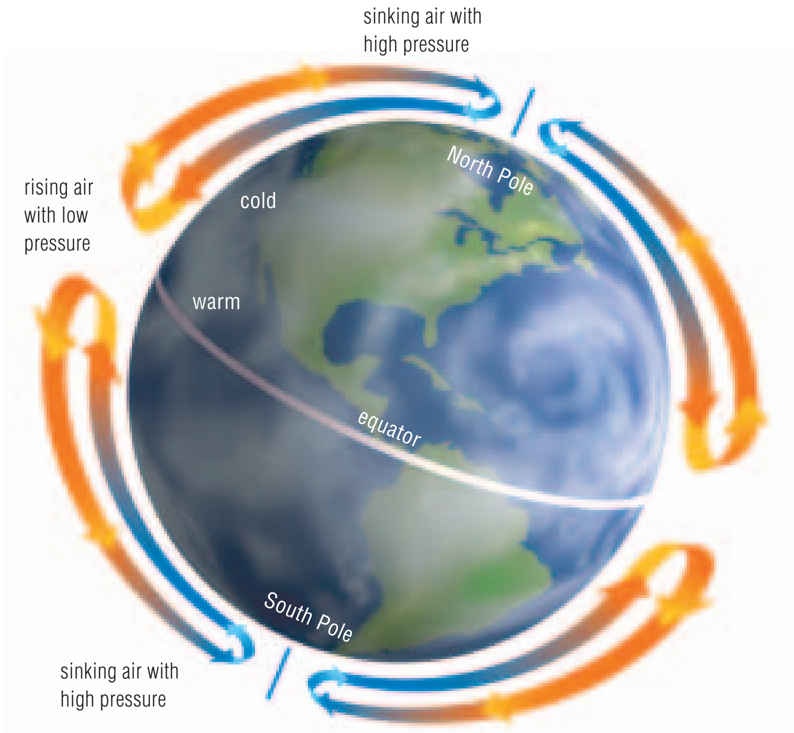


FIGURE D2.20 Differences in thermal energy in the atmosphere would cause these convection currents, if Earth did not rotate.

The Coriolis Effect

The difference between the net radiation budget at the poles and at the equator tends to cause air to move directly north and south. However, since Earth is rotating on its axis, the winds are deflected either toward the right or toward the left. The **Coriolis effect** is the deflection of any object from a straight line path by the rotation of Earth. The Coriolis effect causes moving air or wind to turn right in the Northern Hemisphere and left in the Southern Hemisphere.

Activity D10

QuickLab

The Coriolis Effect

Purpose

To model the Coriolis effect

Materials and Equipment

piece of cardboard at least 30 cm wide

nail or large pin

pen or marker

Procedure

1. Cut a circle of at least 30 cm in diameter from a piece of cardboard. Put the nail or pin into the exact centre of the circle so that it spins freely.
2. Label the centre of the circle as the North Pole, and the outer edge as the equator.
3. Draw a clockwise arrow on the circle at the edge, to indicate the direction of Earth's rotation.
4. To demonstrate the Coriolis effect, have a partner rotate the circle as you draw a straight line from the North Pole to the equator.

Questions

1. Look at the line drawn on the cardboard circle. Which direction does the line twist?
2. What does the twisting line represent?
3. How did this activity model the Coriolis effect?
4. If you repeated this activity on the underside of the circle, which way would the lines twist?

To better visualize the Coriolis effect, imagine you were to launch a rocket at high speed southward from the North Pole. Your rocket would not just travel a straight line south from where you launched it. As the rocket travelled south, Earth would be rotating beneath it, deflecting the path of the rocket westward to the right. If you launched the rocket from the South Pole to the equator instead, the Earth's rotation would again deflect the path of the rocket westward, which is now to the left (Figure D2.21).

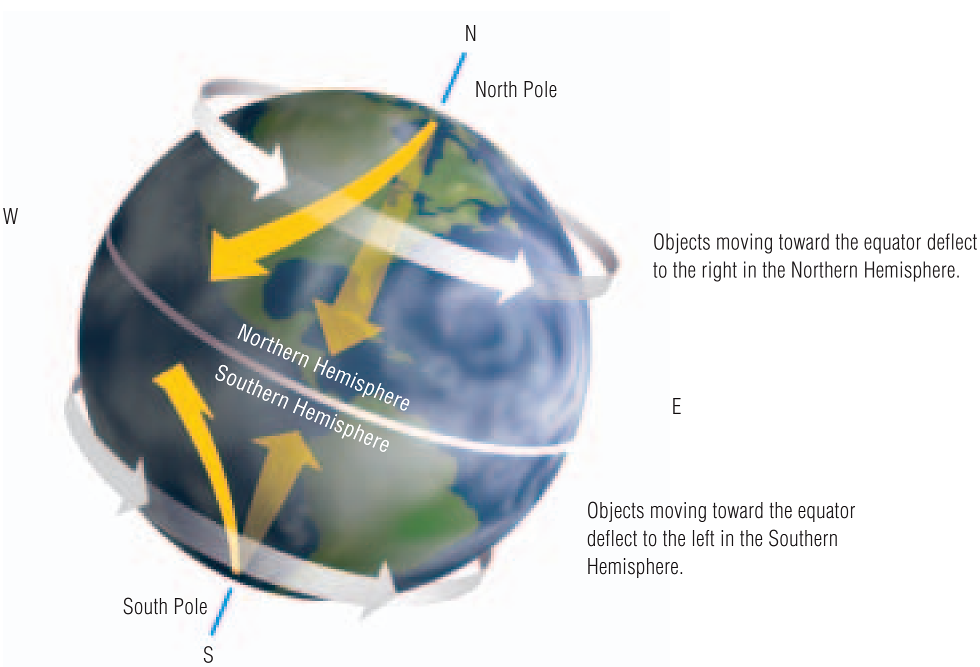


FIGURE D2.21 Winds in the two hemispheres of Earth move in opposite directions because of the Coriolis effect.

info **BIT**

The Cape Denison-Commonwealth Bay region of Adelie Land, Antarctica is the windiest place on Earth. The mean annual wind speed is 90 km/h, but winds can reach speeds up to 320 km/h.

Global Wind Patterns

The convection currents in the atmosphere and the Coriolis effect result in the global wind patterns shown in Figure D2.22. Global winds transfer thermal energy from areas of net radiation budget surplus to areas of net radiation budget deficit. If this did not occur, areas at or near the equator would grow very hot while the rest of Earth would become much colder.

In regions at and near the equator, the rising current of air causes winds that blow steadily northeast and southeast, called the trade winds. Trade winds are caused by the action of the Coriolis effect, which deflects the rising currents of air to the northeast in the Northern Hemisphere and the southeast in the Southern Hemisphere. At latitudes of about 30° N and 30° S, some of the warm air from the equator is sufficiently cooled that it begins to sink and move back toward the equator. The rest of the warm air moves toward the poles and is pushed east by the Coriolis effect, which causes cold air to rush in, in a westward direction. This gives rise to the westerly winds that prevail at the latitudes between 30° and 60° in both directions from the equator. At the poles, sinking cold air is pushed eastward, forming easterly winds.

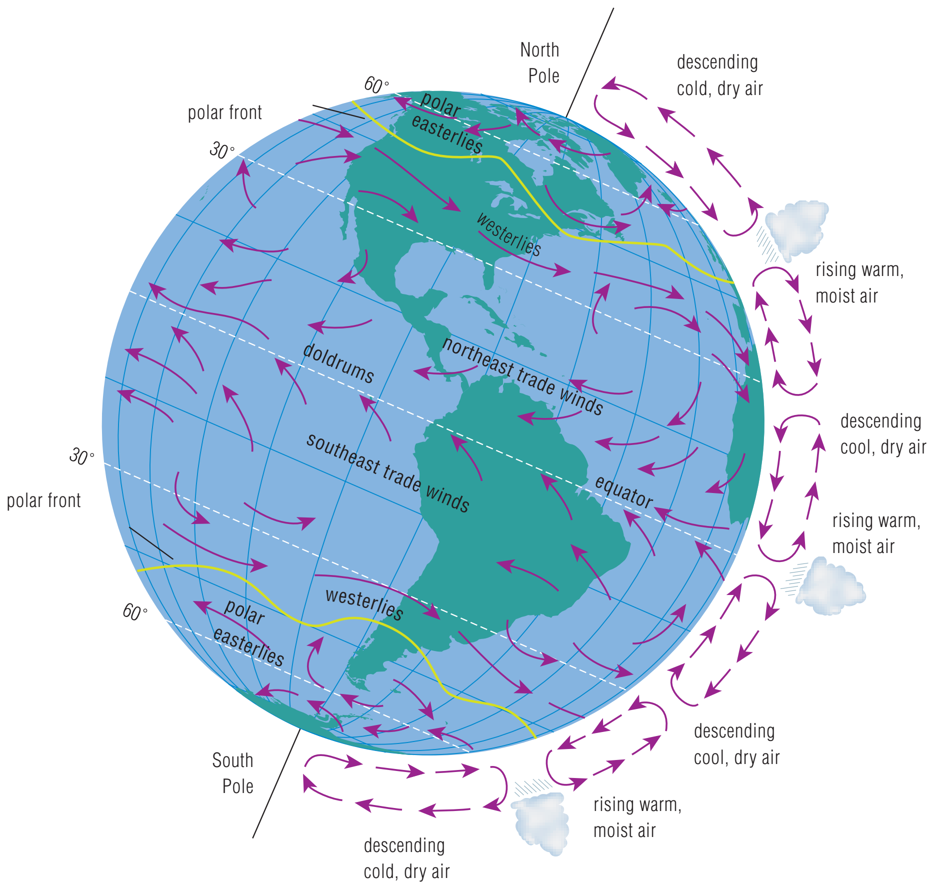


FIGURE D2.22 Global wind patterns are caused by the unequal heating of Earth's atmosphere and the deflection of winds by the Coriolis effect. The trade winds and polar easterlies tend to blow to the east, and the westerlies tend to blow to the west. The doldrums are a region of very low winds in a band about the equator.

Jet Streams

Local conditions such as the presence of continents or large bodies of water also affect wind patterns. Earth's surface and the density of the troposphere produce friction, which slows global winds. A **jet stream** is a band of fast-moving air in the stratosphere. Because of their high altitude, these winds are not subject to as much friction, and so are much faster than winds closer to Earth's surface.

Earth has several jet streams, which circle Earth at various latitudes. There are usually two or three jet streams in the Northern Hemisphere and in the Southern Hemisphere. Like the surface winds, jet streams are also formed by the convection currents in Earth's atmosphere. Their speed and temperature vary with the amount of thermal energy in the atmosphere. During the cooler months, the jet streams tend to be closer to the equator and to move more quickly. Changes in the jet streams affect the formation of severe weather events such as squalls, storms, and cyclones. The movements of the jet streams, particularly those in polar regions, can also affect the movement of the air at lower levels of the atmosphere. Changes in the jet streams are therefore very important to predicting weather changes, and so you are likely to hear them mentioned during weather forecasts.

reSEARCH

Jet streams were first discovered by pilots during the Second World War. The pilots noticed that it took less time to fly to Britain from the United States than it did to fly from the United States to Britain. Using print and electronic resources, find out how the aviation industry uses jet streams today. Begin your search at

www.pearsoned.ca/school/science10

D2.2 Check and Reflect

Knowledge

1. Describe the effect of the unequal distribution of thermal energy on Earth on the temperature of the atmosphere.
2. Name three methods of thermal energy transfer.
3. Compare and contrast conduction and convection.
4. Identify what is transferred by global winds.
5. Explain why air moves from areas of high atmospheric pressure to areas of low atmospheric pressure.
6. Describe the Coriolis effect.
7. Explain how the Coriolis effect influences the direction of wind in the Northern Hemisphere.
8. What are the trade winds and where do they occur?
9. What are jet streams?
10. Explain why jet streams are faster than other global winds.

Applications

11. Create a diagram to illustrate how convection transfers heat.
12. If a high-pressure system is approaching from the west, predict the direction in which the winds will most likely be blowing. Explain your answer.
13. Explain why the air at the equator moves toward the poles.
14. Draw an illustration showing the deflection of the path of a rocket launched in a direct line from the equator toward the North Pole. Would the path of the rocket be deflected in the same way if it were launched in a direct line from the equator toward the South Pole? Explain.

Extensions

15. Describe how conditions in the biosphere might differ if air transferred thermal energy by conduction, instead of by convection.
16. Suppose a planet was discovered that was Earth's twin in all physical and geographic features, except that the planet did not rotate. How would the pattern of global winds on this planet compare to those of Earth?
17. The trade winds were once very important to sailing ships that travelled between Europe and South America. Suggest a reason to explain this fact.

D 2.3 Thermal Energy Transfer in the Hydrosphere

info BIT

El Niño (little boy) is a regularly occurring change in weather patterns caused by changes in ocean currents. El Niño occurs when an unusually warm surface ocean current displaces colder seas in the eastern and central Pacific Ocean and interacts with the atmosphere above. El Niño has been linked to flooding, droughts, high winds, and other severe weather events. Its counterpart, La Niña (little girl), is associated with colder-than-usual sea surface temperatures in the region.

The hydrosphere transfers thermal energy from the warmer latitudes near to the equator to cooler areas near the poles, through the action of global winds. Figure D2.23 shows the major pattern of the surface currents of Earth's oceans. The warmer waters near the equator are driven by the trade winds that prevail between the equator and latitudes 30° N and 30° S. The westerly winds that prevail between latitudes 30° and 60° N and S tend to bring warm waters down toward the poles, and the easterlies that prevail from latitudes 60° N and S to the poles tend to drive cooler waters up toward the equator. As with global winds, the pattern of surface ocean currents is modified by the Coriolis effect. Currents in the Northern Hemisphere are driven clockwise, and currents in the Southern Hemisphere are driven counterclockwise. Earth's continents also affect the general pattern of the ocean's currents, however. The currents change direction when they encounter a large land mass. Some coastal regions, such as the west coast of British Columbia, experience a continuous current of warm water, whereas other regions, such as the east coast of Labrador, experience a continuous current of cold water.

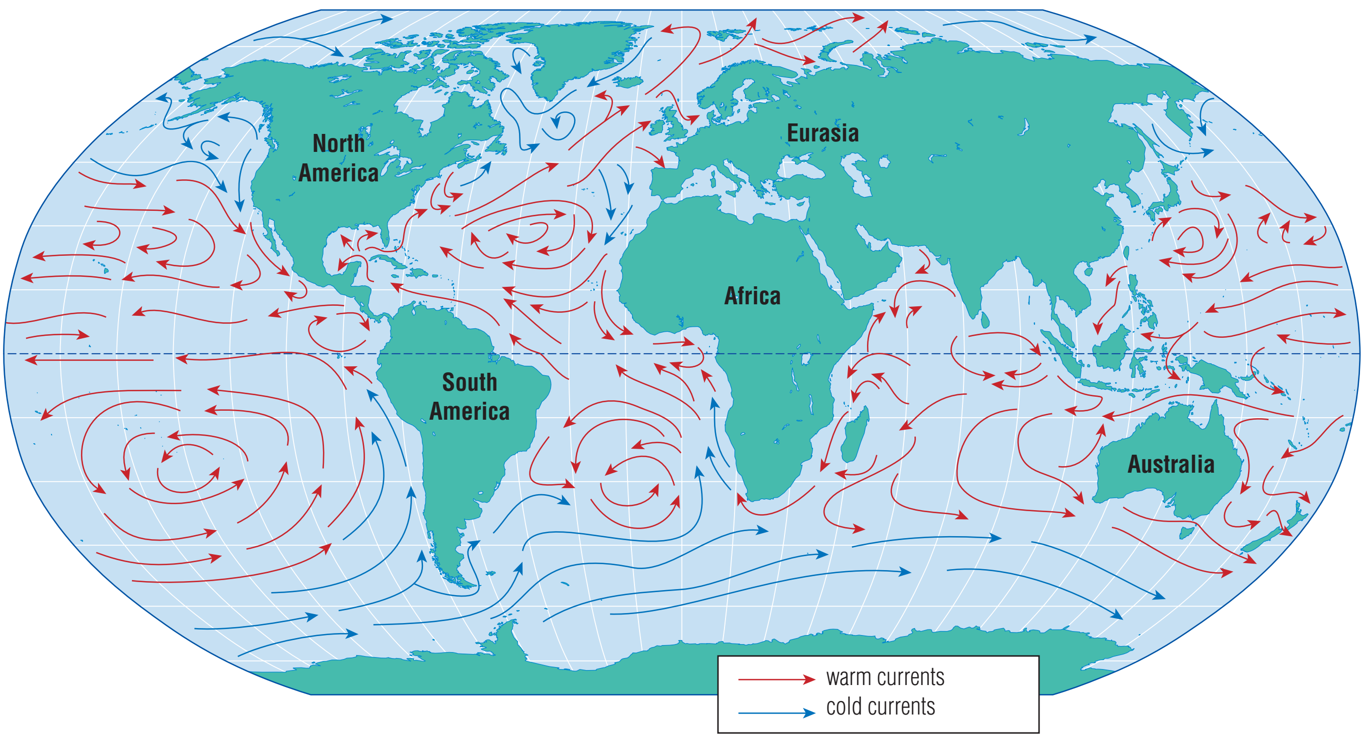


FIGURE D2.23 The surface ocean currents extend from the surface of the ocean to a depth of about 100 m, and reflect the pattern of Earth's global winds.

Thermal energy is also transferred vertically through the oceans and other bodies of water, through convection currents (Figure D2.24). As does air, the density of water decreases when its temperature increases, so warm water tends to rise. Cooler water is more dense, so it tends to sink.

Specific Heat Capacity

Earlier in this unit, you were asked to consider the climates of three Canadian cities: Vancouver, BC (latitude 49.11° N), Lethbridge, AB (49.38° N), and Gander, NF (48.56° N). Since they are at similar latitudes, you now know that these three cities receive similar insolation, and experience similar winds (westerlies). Yet the average temperatures of these cities between 1971 and 2000 varied considerably, according to Environment Canada records (Table D2.1).

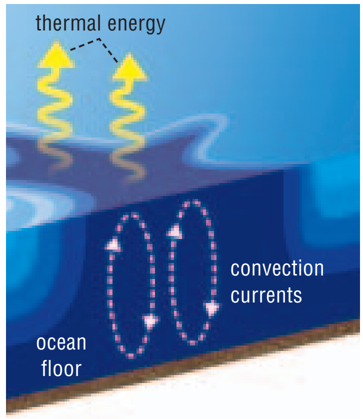


FIGURE D2.24 Convection currents transfer thermal energy between the upper and lower depths of the oceans.

TABLE D2.1 Climate Data for Three Canadian Cities

City	Latitude	Average Annual Temperature (°C)	Average January Temperature (°C)	Average July Temperature (°C)
Vancouver, BC	49.11° N	10.1	3.3	17.5
Lethbridge, AB	49.38° N	5.7	−7.8	18.0
Gander, NF	48.56° N	3.8	−7.4	16.0

Data Source: Environment Canada

Vancouver is situated on the west coast (next to a warm ocean current), Lethbridge is in southern Alberta (an area with no large bodies of water), and Gander is situated on the east coast (next to a cold ocean current). Large bodies of water can have a profound effect on climate.

Climate variations in regions at similar latitudes can be caused by differences in the thermal properties of substances in those regions, which can lead to uneven heating and cooling. Every substance has particular thermal properties, one of which is the amount of energy that the substance can absorb before it changes temperature. For example, suppose you have an aluminium lawn chair. One hot summer day, you leave the lawn chair in direct sunlight with a glass of water beside it. If you were to return to the chair in an hour, you would likely find that the aluminium chair was too hot to touch. The water would likely be very warm, but it would not be too hot to touch. Water can absorb a large quantity of thermal energy before it changes temperature.

The **specific heat capacity (*c*)** of a substance is the amount of energy required to raise the temperature of 1 g of the substance by 1°C. The theoretical specific heat capacity of water is 4.19 J/g·°C, whereas the theoretical specific heat capacity of aluminium is 0.897 J/g·°C. Regions on Earth's surface that have little water tend to heat and cool more rapidly than regions at similar latitudes with a lot of water.

Because water has a relatively large specific heat capacity, it takes a considerable amount of energy to increase the temperature of a mass of water (Figure D2.25). Similarly, a large amount of energy is released from a mass of water when the temperature of the water decreases. Water therefore heats up and cools down slowly compared to many other substances. About 70% of Earth's surface is covered by water, so the capacity of water to absorb thermal energy has a great effect on climate. Substances that make up the lithosphere generally have a lower specific heat capacity than water. This in part is why the air temperature tends to vary more with the seasons in Lethbridge than in Vancouver.

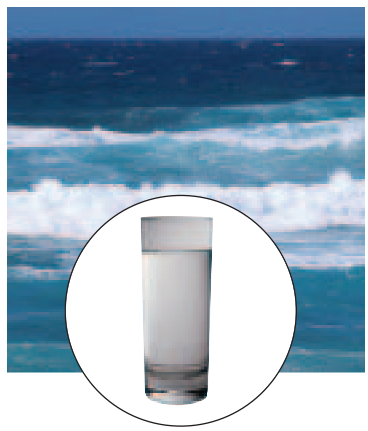


FIGURE D2.25 Specific heat capacity is the amount of energy required to raise the temperature of 1 g of a substance by 1°C. It therefore takes far more thermal energy to increase the temperature of the water in an ocean than in a single glass.

The specific heat capacity of water is also much higher than that of air. As a result, the average air temperature over a body of water varies far less than the air temperature over land in the same region. Water can absorb a large quantity of thermal energy from the atmosphere without changing temperature. As a result, coastal areas experience less variation in temperature than inland areas. Coastal areas also tend to be warmer than non-coastal regions when they are close to warm ocean currents, and cooler when they are close to cool ocean currents. For example, in Vancouver, the warm ocean currents help to maintain relatively warm air temperatures in January, and the relatively warm average annual temperature of 10.1°C. In Gander, the cool ocean currents help to maintain relatively cool air temperatures in July, and the relatively cool average annual temperature of 3.8°C.

Quantity of Thermal Energy, *Q*

The **quantity of thermal energy**, ***Q***, is the amount of thermal energy absorbed or released when the temperature of a specific mass of substance changes by a certain number of degrees. Q can be calculated by the following equation:

$$Q = mc\Delta t$$

where Q is the quantity of thermal energy, in J,
m is the mass of the substance, in g,
c is the specific heat capacity of the substance, in J/g·°C, and
Δt is the change in temperature, in °C.

To determine Q, you must know the value for the specific heat capacity, c, of the substance. The specific heat capacity of a substance can be determined using a calorimeter. A **calorimeter** is any device used to determine the transfer of thermal energy. A calorimeter can be as simple as nested foam coffee cups, like the device shown in Figure D2.26. When you use a calorimeter, you assume that any energy that is released can be detected as a change in the temperature inside the calorimeter. Scientists use calorimeters to determine the specific heat capacities of many substances, which are then published in reference materials.

The other two variables in the equation can be directly measured. Mass is measured in grams, using a balance. The change in temperature is determined by measuring the temperature of a substance before energy is added or removed, and the highest temperature that substance reaches at the end of the experiment.

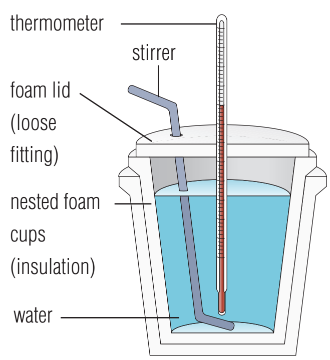


FIGURE D2.26 A simple foam cup calorimeter

Example Problem D2.1

A 50.0-g mass of water at 25.0°C is heated to 50.0°C on a hot plate. Given that the theoretical specific heat capacity of water is 4.19 J/g·°C, determine the value for Q.

$$\begin{aligned} \Delta t &= 50.0°\text{C} - 25.0°\text{C} \\ &= 25.0°\text{C} \end{aligned}$$

The mass, m, is 50.0 g, and the specific heat capacity, c, is 4.19 J/g·°C. Therefore:

$$\begin{aligned} Q &= mc\Delta t \\ &= (50.0\ \cancel{\text{g}})\,(4.19\ \text{J}/\cancel{\text{g}}\cdot°\cancel{\text{C}})\,(25.0°\cancel{\text{C}}) \\ &= 5237.5\ \text{J} \\ &= 5.24\ \text{kJ} \end{aligned}$$

The amount of thermal energy added, Q, was 5.24 kJ.

Practice Problems

1. A 200-g mass of water at 4.00°C is allowed to warm to 22.0°C. Determine the amount of thermal energy, Q, absorbed. The theoretical specific heat capacity of water is 4.19 J/g·°C.
2. A 100.0-g mass of water is at 23.0°C. Determine the quantity of thermal energy, Q, required to increase the temperature of the water to 100.0°C. The theoretical specific heat capacity of water is 4.19 J/g·°C.

Example Problem D2.2

How much thermal energy must be released to decrease the temperature of 1.00 kg of water by 10.0°C, given that the theoretical specific heat capacity of water is 4.19 J/g·°C?

Mass, m, is 1.00 kg or 1000 g. Therefore:

$$\begin{aligned} Q &= mc\Delta t \\ Q &= (1000\ \cancel{\text{g}})\,(4.19\ \text{J}/\cancel{\text{g}}\cdot°\cancel{\text{C}})\,(10.0°\cancel{\text{C}}) \\ &= 41\,900\ \text{J} \\ &= 41.9\ \text{kJ} \end{aligned}$$

To decrease the temperature of 1.00 kg of water by 10°C, 41.9 kJ of thermal energy must be released.

Practice Problems

3. Calculate the amount of thermal energy that must be released to decrease the temperature of 20.0 g of water by 15.0°C, given that the theoretical specific heat capacity of water is 4.19 J/g·°C.
4. Determine the quantity of energy required to warm a 1.00-kg block of ice from −15.0°C to 0°C. The theoretical specific heat capacity of ice is 2.00 J/g·°C.

Provided that three of the variables are known, this equation can be solved for any of Q, m, c, or Δt.

Example Problem D2.3

Calculate the change in temperature, Δt, that occurs when 8.38 kJ of thermal energy is added to 100.0 g of water. The theoretical specific heat capacity of water is 4.19 J/g·°C.

First, convert the amount of energy from kJ to J.

$$8.38 \text{ kJ} = (8.38 \cancel{\text{kJ}})(1000 \text{ J}/\cancel{\text{kJ}})$$
$$= 8380 \text{ J}$$

Then, rearrange the equation as follows:

$$\begin{aligned} Q &= mc\Delta t \\ \text{or, } \Delta t &= \frac{Q}{mc} \\ &= \frac{8380 \cancel{\text{J}}}{(100.0 \cancel{\text{g}})(4.19 \cancel{\text{J}}/\cancel{\text{g}}\cdot°\text{C})} \\ &= 20.0°\text{C} \end{aligned}$$

When 8.38 kJ of thermal energy is added to 100.0 g of water, the temperature changes by 20.0°C.

Practice Problems

5. Calculate the change in temperature, Δt, that occurs when 255 kJ of thermal energy is added to 3.0 kg of water. The theoretical specific heat capacity of water is 4.19 J/g·°C.

6. Calculate and compare the changes in temperature, Δt, that occur when 500 J of thermal energy is removed from 1.00 kg of water, and when 500 J of thermal energy is removed from 1.00 kg of iron. The theoretical specific heat capacity of water is 4.19 J/g·°C, and the theoretical specific heat capacity of iron is 0.449 J/g·°C.

Example Problem D2.4

When 21.6 J of thermal energy is added to a 2.0-g mass of iron, the temperature of the iron increases by 24.0°C. What is the experimental specific heat capacity of iron?

First, rearrange the equation to solve for specific heat capacity, c:

$$\begin{aligned} Q &= mc\Delta t \\ \text{or, } c &= \frac{Q}{m\Delta t} \\ &= \frac{21.6 \text{ J}}{(2.0 \text{ g})(24.0°\text{C})} \\ &= 0.45 \frac{\text{J}}{\text{g}\cdot°\text{C}} \end{aligned}$$

The experimental specific heat capacity of iron is 0.45 J/g·°C. Although the theoretical specific heat capacity of iron is 0.449 J/g·°C, the experimental value is slightly higher. The difference is due to the limits of accuracy in measurement. Accuracy is indicated by the number of significant digits.

Practice Problems

7. When 574 J of thermal energy is added to 20.0 g of aluminium, the temperature of the aluminium increases by 32.0°C. What is the experimental specific heat capacity of aluminium?

8. Calculate the experimental specific heat capacity of an object of mass 1.00 kg, given that the object releases 1.95 kJ of heat when its temperature decreases by 15.0°C.

Activity D11

Inquiry Lab

Student Reference 5

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Investigating Specific Heat Capacity

CAUTION: In this lab, you will work with solids and liquids heated to 100°C. Use extreme care. If you are unsure of any steps in the procedure, ask before you proceed.

Changes in the quantity of thermal energy, Q, of any substance can be determined by measuring the change in temperature of the water within a simple calorimeter. This method assumes that, when the substance is placed inside, all the thermal energy released or absorbed by the substance is absorbed or released by the water in the calorimeter. In this investigation, you will raise the temperature of two substances from room temperature to 100.0°C. You will then use a calorimeter and the equation $Q = mc\Delta t$ to determine the specific heat capacities of the substances from your experimental data. Finally, you will compare your experimental values with the theoretical values.

The Question

How different are the specific heat capacities of iron and copper?

Variables

The manipulated variable is specific heat capacity. What is the responding variable?

Materials and Equipment

small piece of iron	thermometer
small piece of copper	tongs
2 foam cups	stirring rod
foam lid to fit foam cups	100-mL graduated cylinder
250-mL beaker	balance
hot plate	

Procedure

1. Read through the procedure, and then design a data table to record your observations. Your data table will need space for at least five entries for each substance.
2. Make a simple calorimeter by first placing one of the foam cups into the other. Then make a hole in the foam lid that is large enough to insert the thermometer. Make a second hole to fit the stirring rod.
3. Using the balance, determine the masses of the iron and the empty calorimeter. Record the masses in your data table.
4. Add 100 mL of water to a 250-mL beaker. Place the beaker on the hot plate and bring the water to a boil. One person in your group must always monitor the water.
5. Determine the temperature of the boiling water to the nearest 0.1°C. Record your observation.
6. Place the piece of iron into the boiling water for 5 min.
7. While the iron is in the boiling water, pour 50 mL of room-temperature water into the calorimeter. Determine the initial temperature of the water in the calorimeter to the nearest 0.1°C, and record your observation.
8. After 5 min have passed, use the tongs to carefully remove the iron from the boiling water. Immediately place the iron into the calorimeter so that the iron is completely submerged. If necessary, add additional room-temperature water. Attach the lid, and insert the thermometer and stirring rod. Make sure the thermometer is not touching the piece of iron.
9. Gently stir the water in the calorimeter with the stirring rod. Measure and record the maximum temperature reached by the water in the calorimeter, to the nearest 0.1°C.
10. Remove the metal, thermometer, and stirring rod, and then determine the mass of the water in the calorimeter.
11. Repeat steps 1 through 10, using a small piece of copper.

Analyzing and Interpreting

1. Calculate the temperature change, Δt, of the water in the calorimeter after the iron was added.

2. Determine the amount of heat, Q, that was absorbed by the water in the calorimeter after the iron was added. The theoretical specific heat capacity of water is 4.19 J/g·°C.

3. Calculate the temperature change, Δt, for the piece of iron.

4. Using the mass of the iron and the equation $Q = mc\Delta t$, calculate your experimental value for the specific heat capacity of iron. Assume that the quantity of thermal energy, Q, released by the iron is equal to the quantity of thermal energy absorbed by the water.

5. Repeat steps 1 to 4, using your data for the piece of copper.

6. The theoretical value for the specific heat capacity of iron is 0.449 J/g·°C. The theoretical value for the specific heat capacity of copper is 0.385 J/g·°C. Determine the percent error of your experimental values for the specific heat capacity of iron and of copper. Percent error can be calculated from the following formula:

$$\text{percent error} = \left|\frac{(\text{experimental value} - \text{theoretical value})}{\text{theoretical value}}\right| \times 100\%$$

Forming Conclusions

7. Compare the specific heat capacities of iron and copper, referring to your data. Write a lab report summarizing your experiment.

8. In a paragraph, compare the temperature change of the iron to the temperature change of the water. Assuming that all the thermal energy lost by the iron was transferred to the water, comment on the effect of the specific heat capacity of water on maintaining Earth's average global temperature.

9. Discuss how differences in the specific heat capacity of substances can contribute to uneven heating and cooling of Earth's surface.

The Hydrologic Cycle and Energy Transfer

The water of the hydrosphere may be present as liquid water, as solid ice or snow, or as water vapour in the atmosphere. Water molecules are also found within the cells and tissues of the living organisms found in the biosphere. Water molecules are constantly moving among the components of the biosphere through the action of the **hydrologic cycle** (also called the **water cycle**). At various stages in the hydrologic cycle, water molecules undergo change in **phase** (state), from solid to liquid to vapour, and back again

As shown in Figure D2.27, water leaves the atmosphere as precipitation, either as a solid (snow or hail) or as a liquid (rain). Some of the solid precipitation then melts and returns to the liquid phase. Most of the liquid water from precipitation collects in large bodies of water such as lakes and oceans, and a smaller amount stays in the soil of the lithosphere. All living organisms, including plants, take in water for use in cellular processes and then release water back to the atmosphere as water vapour during respiration. Plants also take up a proportion of the liquid water in the biosphere and use it for photosynthesis. Transpiration brings water up from the soil in the lithosphere through the roots. Any water that is not used by the plant is then returned to the atmosphere as water vapour, through microscopic pores in the plant's leaves. Most water (about 90%) returns to the atmosphere through evaporation from large bodies of water on Earth's surface. During evaporation, water changes from the liquid phase to the vapour phase. The hydrologic cycle therefore moves water between the components of the biosphere.

info **BIT**

It is estimated that there are about 1.39 billion cubic kilometres of water on Earth, but only 12 900 cubic kilometres are in the atmosphere at any one time. If all the water were to fall out of the atmosphere, the lithosphere would be covered in an average depth of water of 2.5 cm.

Whenever water changes phase, thermal energy is either released or absorbed. The temperature of the water remains the same during a phase change, even though the quantity of thermal energy increases or decreases. Thermal energy is released when water goes from liquid to solid. When liquid water changes to water vapour, thermal energy is absorbed. Through such changes of state, the hydrologic cycle therefore also transfers thermal energy through the biosphere.

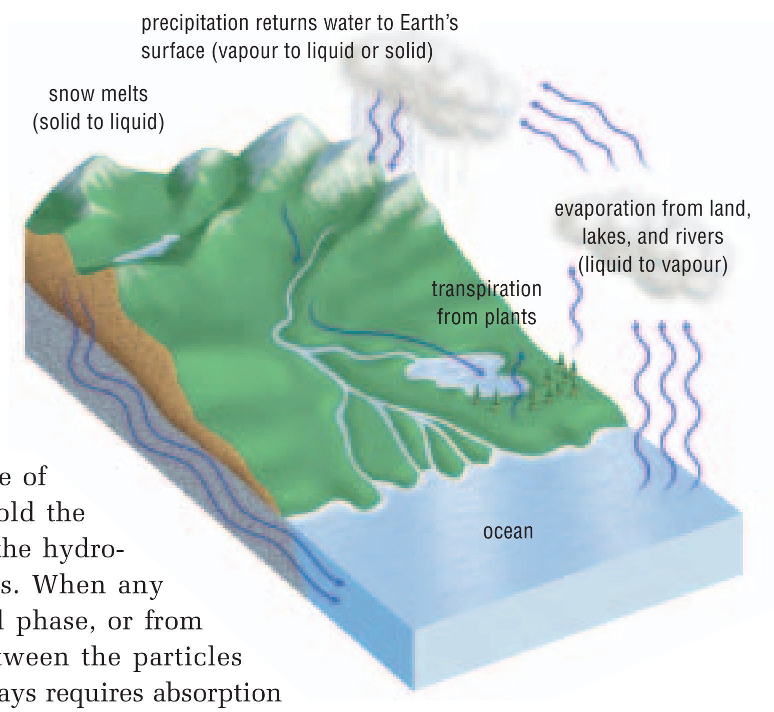


FIGURE D2.27 The hydrologic cycle involves many phase changes.

The hydrologic cycle also moves thermal energy, through absorption and release of energy by the attractive forces (bonds) that hold the water molecules together. Recall that during the hydrologic cycle, water changes phase many times. When any substance changes from solid phase to liquid phase, or from liquid phase to vapour phase, the bonds between the particles become weaker and break. Breaking bonds always requires absorption of energy. In contrast, when any substance changes from vapour phase to liquid phase, or from vapour phase to solid phase, new bonds are formed between the particles. Bond formation always releases energy. When energy is released or absorbed by the bonds between particles during a phase change, energy is transferred. However, when bonds break or form during a phase change, the temperature of the substance does not change. Temperature change only occurs when there is an increase or decrease in the kinetic energy of the particles. Since the energy is used to break bonds between the particles, this energy is not available to increase the kinetic energy of the particles.

Since water molecules undergo many phase changes during the hydrologic cycle, a lot of energy is transferred in the biosphere without any changes in temperature of the water. This helps to keep the average temperature of Earth relatively stable. For example, incoming solar energy used to break bonds, and so evaporate water molecules from the ocean or melt snow on land, is not available to increase the temperature of any component of the biosphere.

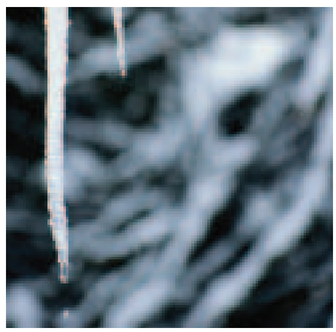


FIGURE D2.28 Thermal energy is released when water changes from the liquid phase to the solid phase.

Heat of Fusion and Heat of Vaporization

The **heat of fusion** of a substance is the amount of energy absorbed when 1 mol of the substance changes from solid phase to liquid phase, without a change in temperature. The energy released during the reverse phase change, when 1 mol of a solid forms, is referred to as the **heat of solidification** (Figure D2.28). The **heat of vaporization** of a substance is the amount of energy absorbed when 1 mol of the substance changes from liquid phase to vapour phase, without a change in temperature (Figure D2.29). The energy released during the reverse phase change, when 1 mol of a vapour condenses to a liquid, is called the **heat of condensation**.

FIGURE D2.29 Thermal energy is absorbed by water as it changes from the liquid phase to the vapour phase.

Activity D12

QuickLab

Temperature and Phase Change

CAUTION: To avoid a burning injury, handle the heated water carefully.

Purpose

To observe the temperature changes of water as it changes phase

Materials and Equipment

250-mL beaker

hot plate

retort stand

clamp

thermometer or temperature probe

crushed ice

timer or clock

graph paper, graphing calculator, or spreadsheet software

Procedure

1. In your notebook or a spreadsheet file, construct a data table similar to the one shown. You will need more rows than in the example.

2. Add crushed ice to the beaker until it is about half full.

Time (s)	Temperature (°C)

3. Place the beaker on a hot plate. Carefully place the thermometer in the ice. The bulb of the thermometer should be just above the bottom of the beaker. Attach the thermometer to the clamp on the retort stand. Turn on the hot plate to its highest setting.

4. Wear heat-proof protective gloves while working. Measure and record the temperature of the ice–water mixture every 30 s, until the water in the beaker has boiled for 3 min.

5. Turn off the hot plate.

Questions

1. Construct a line graph of your data.
2. In one or two sentences, describe the shape of your graph.
3. Based on your data, explain what happens to the temperature of water as it changes phase from solid to liquid and from liquid to gas (water vapour).
4. Identify the manipulated and the responding variable in this investigation.

In Activity D12 QuickLab, you heated a beaker of ice until the water turned to steam. During heating, the water underwent two phase changes: first from solid to liquid, then from liquid to gas. The temperature of the water remained at about 0°C for all the time that ice remained in the beaker. While the water was boiling, the temperature remained at about 100°C. These results are shown graphically in Figure D2.30, the heating curve of water.

When thermal energy was first added to the ice, the temperature of the ice increased. During this stage of the experiment, the absorbed thermal energy was converted to kinetic energy of the water molecules. This was detected as an increase in temperature. When water changed phase from solid to liquid, the temperature of the water remained at 0°C for some time,

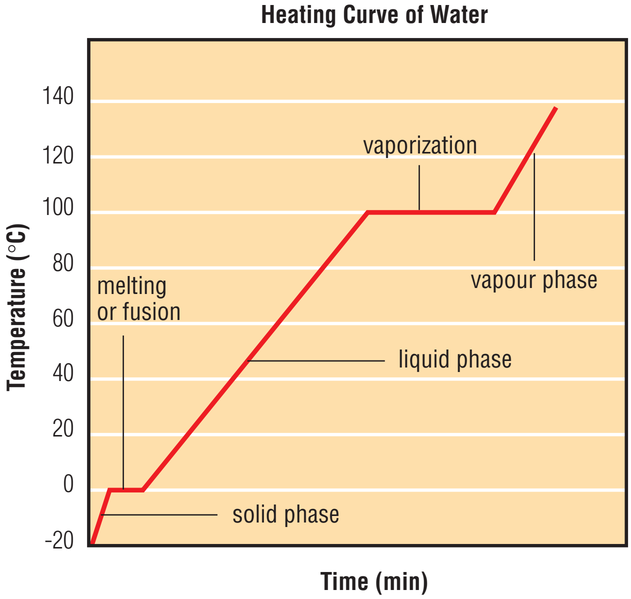


FIGURE D2.30 The temperature of water remains constant during a phase change. The temperatures shown are for water at sea level. The exact temperatures at which phase changes occur will vary slightly with changes in altitude. The shape of the graph will always be the same, however.

which is shown by the first flat area in the heating curve, and is labelled "melting or fusion." At this stage, the absorbed thermal energy was no longer being converted to kinetic energy, but was absorbed by the forces between the water molecules. When these forces gained sufficient potential energy, they became disrupted, and the water changed from solid phase to liquid phase. After this phase change was completed (when all the ice was melted), the thermal energy absorbed by the liquid water was again converted into kinetic energy, so the temperature of the liquid water rose. At the boiling point of water, the absorbed thermal energy again was absorbed by the intermolecular forces, causing them to break. We know this because the temperature of the water again remained constant, giving rise to the second flat area on the heating curve, at 100°C.

Calculating Heat of Fusion and Heat of Vaporization

The amount of energy absorbed or released during a phase change from solid to liquid by a known amount of any substance can be calculated from the following formula:

$$H_{fus} = \frac{Q}{n},$$

where H_{fus} is the heat of fusion, in kJ/mol,
Q is the quantity of thermal energy, in kJ, and
n is the amount of the substance, in mol.

To determine H_{fus}, you must know the quantity of thermal energy that was added and the molar amount of the substance. Scientists have determined the heats of fusion of many substances, and these values are available in reference sources. The equation for H_{fus} may be rearranged and used to solve for either the quantity of thermal energy or the molar amount of a substance, using these published values. The theoretical heat of fusion of ice is 6.01 kJ/mol.

Practice Problems

9. When 0.751 kJ of thermal energy is added to 0.125 mol of ice at 0.0°C, the ice changes phase. Calculate the experimental heat of fusion of ice.

10. How much thermal energy is required to completely melt 3.20 mol of ice at 0.0°C?

11. Calculate the amount in moles of ice at 0.0°C that can be melted by addition of 15.0 kJ of thermal energy.

Example Problem D2.5

When 27.05 kJ of thermal energy is added to 4.50 mol of ice at 0.0°C, the ice melts completely. What is the experimental heat of fusion of water?

$$\begin{aligned} H_{fus} &= \frac{Q}{n} \\ &= \frac{27.05\ \text{kJ}}{4.50\ \text{mol}} \\ &= 6.0111111\ \frac{\text{kJ}}{\text{mol}} \\ &= 6.01\ \frac{\text{kJ}}{\text{mol}} \end{aligned}$$

The heat of fusion of ice is 6.01 kJ/mol.

Although the theoretical value for H_{fus} of ice is 6.01 kJ/mol, the experimental value is slightly higher than this before rounding, due to the limits of accuracy in measurement. The level of accuracy is indicated by the number of significant digits in the final answer.

If the mass (m) of a substance is given or required, the amount (n) must first be determined by converting from g to mol, using the equation below:

$$n = \frac{m}{M}$$

where n is the amount of the substance, in mol
m is the mass of the substance, in g, and
M is the molar mass of the substance, in g/mol.

Example Problem D2.6

When 5.00 g of ice melts, 1.67 kJ of thermal energy is absorbed. Calculate the experimental heat of fusion of ice. The molar mass, M, of ice is 18.02 g/mol.

First determine the number of moles, n, in 5.00 g of ice:

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{5.00\ \cancel{\text{g}}}{18.02\ \cancel{\text{g}}/\text{mol}} \\ &= 0.2774694\ \text{mol} \end{aligned}$$

You can now determine H_{fus}

$$\begin{aligned} H_{fus} &= \frac{Q}{n} \\ &= \frac{1.67\ \text{kJ}}{0.2774694\ \text{mol}} \\ &= 6.01868\ \frac{\text{kJ}}{\text{mol}} \\ &= 6.0\ \frac{\text{kJ}}{\text{mol}} \end{aligned}$$

The experimental heat of fusion of ice is 6.0 kJ/mol, given to the correct number of significant digits.

Practice Problem

12. Determine the experimental heat of fusion of copper, given that it takes 0.606 kJ of thermal energy to melt 100 g of solid copper at its melting point. The molar mass of copper is 63.55 g/mol.

The second flat area on Figure D2.30 is due to the absorption of thermal energy required to vaporize the water. The heat of vaporization for water is 40.65 kJ/mol. The heat of vaporization can be calculated by:

$$H_{vap} = \frac{Q}{n}$$

where H_{vap} is the heat of vaporization, in kJ/mol,
Q is the quantity of thermal energy, in kJ, and
n is the amount of the substance, in mol.

As for H_{fus}, if the mass (m) of the substance changing phase is given or required, the amount (n) of the substance can be determined by converting from grams to moles, using the molar mass (M) of the substance, before the equation for H_{vap} is used.

*re*SEARCH

Investigate why farmers spray their crops with water if there is chance of frost during the growing season. Begin your search at www.pearsoned.ca/school/science10

Example Problem D2.7

When 150 g of water changes from liquid to vapour phase, 339 kJ of energy is absorbed. Determine the experimental heat of vaporization of water, given that the molar mass, M, of water is 18.02 g/mol.

First determine the number of moles, n, in 150 g of water, using the molar mass:

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{150\ \cancel{g}}{18.02\ \cancel{g}/\text{mol}} \\ &= 8.32\ \text{mol} \end{aligned}$$

You can now determine experimental H_{vap}.

$$\begin{aligned} H_{vap} &= \frac{Q}{n} \\ &= \frac{339\ \text{kJ}}{8.32\ \text{mol}} \\ &= 40.745192\ \frac{\text{kJ}}{\text{mol}} \\ &= 40.7\ \frac{\text{kJ}}{\text{mol}} \end{aligned}$$

The experimental heat of vaporization of water is 40.7 kJ/mol.

Note that the theoretical value for H_{vap} is 40.65 kJ/mol. The experimental value is slightly higher than this, due to the limits of accuracy in measurement, indicated by rounding the final answer to the correct number of significant digits.

Practice Problems

13. When 8.70 kJ of thermal energy is added to 2.50 mol of liquid methanol, all the methanol enters the vapour phase. Determine the experimental heat of vaporization of methanol.

14. When 250 g of liquid water evaporates, 564.0 kJ of thermal energy is absorbed. Determine the experimental heat of vaporization of water, given that water has a molar mass, M, of 18.02 g/mol.

15. Calculate the amount of thermal energy required to change 500 g of water from the liquid phase to the vapour phase. The molar mass of water is 18.02 g/mol, and the theoretical heat of vaporization of water is 40.65 kJ/mol.

Activity D13

Inquiry Lab

Student Reference 6

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Thermal Energy and Melting Ice

The Question

How much thermal energy is required to change the phase of water from solid to liquid?

Materials and Equipment

2 foam cups	thermometer
stirring rod	ice cubes
balance	paper towels
100-mL graduated cylinder	water

Procedure

1. Make a calorimeter by placing one foam cup inside the other.
2. Using the balance, measure and record the mass of the empty calorimeter, including the thermometer and stirring rod. Ensure that the calorimeter does not tip over.
3. Using the graduated cylinder, add 50 mL of hot tap water to the calorimeter. The temperature of the water should be about 50°C.
4. Measure the mass of the calorimeter and water, including the stirring rod and thermometer. Calculate and record the mass of the water alone.
5. Measure and record the temperature of the water in the calorimeter to the nearest 0.1°C.
6. With a paper towel, dry any water from two or three ice cubes and then add them to the calorimeter. Stir the mixture with the stirring rod. As soon as the ice cubes melt, measure and record the temperature of the water.
7. Using the balance, determine the mass of the full calorimeter. Calculate and record the mass of the melted ice cubes.

Analyzing and Interpreting

1. Calculate the amount of heat transferred from the water to the ice cubes, using the mass of the melted ice cubes and the equation $Q = mc\Delta t$.

2. Given that the molar mass, M, of water is 18.02 g/mol, calculate the number of moles of ice that you added, using the following equation:

$$n = \frac{m}{M}$$

3. Use your data to calculate the experimental heat of fusion of ice in kJ/mol, using the following equation:

$$H_{fus} = \frac{Q}{n}$$

4. The theoretical value of H_{fus} of ice is 6.01 kJ/mol. Determine the percent error of your value using the following formula:

$$\text{percent error} = \left|\frac{(\text{experimental value} - \text{theoretical value})}{\text{theoretical value}}\right| \times 100\%$$

Forming Conclusions

5. Write a summary of your findings. Compare the accepted value for H_{fus} of water with the value you calculated from your data. Identify the sources of error for your experimental value.

Activity D14

Design a Lab

Student Reference 2

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Variables Affecting the Evaporation of Water

Many variables can affect the rate at which water evaporates. In this investigation, you will design a controlled experiment that will allow you to determine how one variable, that you select, affects the rate of water evaporation.

The Question

How does one particular variable affect the rate of evaporation of water?

Design and Conduct Your Investigation

1. Make a list of variables that you think are likely to influence the rate of evaporation of water.
2. For each variable on your list, write a hypothesis that predicts how changes in that variable will affect the rate of evaporation of water.
3. Write a plan for an investigation that will test the effect of one of these variables on the rate of evaporation of water. Clearly outline all the steps that you will follow to complete your investigation. Identify the variables that you will control and the variable that will be manipulated.
4. List all the materials and equipment you will need to carry out your investigation. Include only materials that you can find at home or in the science classroom.
5. List all the safety precautions that need to be followed in your experiment.
6. Turn in your completed procedure to your teacher. Do not proceed until your teacher has approved your procedure.
7. Perform your experiment.
8. Analyze your results. Do your data support your hypothesis?
9. Compare your experimental design and procedure with those of your classmates. Identify any strengths and weaknesses that are in the different experimental designs.
11. State any problems or questions that you found during your investigation or analysis, that would need additional investigation to answer.

Phase Changes and Global Energy Transfer

The phase changes that occur in the hydrologic cycle play a significant role in the global transfer of thermal energy. When it evaporates, water absorbs 40.65 kJ of thermal energy per mol. When water vapour condenses into liquid water, an equivalent amount of thermal energy per mol is released into the atmosphere, which warms the air. This warmed air becomes less dense and rises. Rising air can sometimes start thunderstorms (Figure D2.31), or even hurricanes.

FIGURE D2.31 Thermal energy released by phase changes in water can cause severe weather events.

D2.3 Check and Reflect

Knowledge

1. Describe how thermal energy is transferred through the hydrosphere.
2. Show how water moves through the biosphere in a cyclic manner.
3. Identify the sources of water vapour in the atmosphere.
4. State the percent of Earth's surface that is covered by water.
5. Create a pie chart illustrating the sources of water vapour in the atmosphere.
6. Define the term "specific heat capacity."
7. Identify the factors that must be considered in order to determine the specific heat capacity of any substance.
8. The theoretical specific heat capacity of water is 4.19 J/g·°C. Aluminium has a theoretical specific heat capacity of 0.897 J/g·°C. If 1.00 g of water and 1.00 g of aluminium are both heated to 50.0°C, which substance will contain the greater quantity of thermal energy?
9. Write an equation for the heat of fusion, and define each term in the equation.
10. Define the term "heat of vaporization."
11. What is the difference between the heat of fusion and the heat of vaporization of a substance?

Applications

12. Describe any similarities between global wind patterns and global ocean current patterns.
13. A large island, surrounded by ocean, has two cities at the same latitude. One city is situated on the west coast, and the other on the east coast. Cold ocean currents travel along the west coast of the island, and warm ocean currents travel along the east coast. Which city do you predict would have the warmer average annual temperature? Explain your answer.
14. Calculate the amount of thermal energy required to raise the temperature of 3.0 kg of aluminium from 20.0°C to 80.0°C. The theoretical specific heat capacity of aluminium is 0.897 J/g·°C.
15. Calculate the amount of thermal energy required to increase the temperature of 2.00 kg of water by 20.0°C. The theoretical specific heat capacity of water is 4.19 J/g·°C.
16. A 2.50-g mass of iron is at 24.0°C. Determine the final temperature of the iron after it absorbs 13.5 J of thermal energy. The theoretical specific heat capacity of iron is 0.449 J/g·°C.
17. When 60.0 J of thermal energy is added to a mass of copper, the temperature of the copper increases by 10.4°C. The specific heat capacity of copper is 0.385 J/g·°C. What mass of copper was heated?
18. Calculate the experimental heat of vaporization of water, given that it requires 81.4 kJ of thermal energy to vaporize 2.00 mol of liquid water at 100.0°C.
19. Explain why 100.0 g of liquid water at 100.0°C contains less thermal energy than 100.0 g of water vapour at 100.0°C.
20. Calculate the amount of energy absorbed when 45.0 g of ice at 0.0°C melts. The theoretical heat of fusion of water is 6.01 kJ/mol, and the molar mass of water is 18.02 g/mol.
21. Determine how many moles of water at 100.0°C will change from the liquid to the vapour phase by absorption of 488 kJ of thermal energy. The theoretical heat of vaporization of water is 40.65 kJ/mol.

Extensions

22. Explain why water in a lake is warmer in the fall than in the spring.
23. A glass of water with ice cubes in it is left in a room at 24.0°C. Explain why the temperature of the water will remain at 0.0°C, until all the ice is melted.

D 2.4 Earth's Biomes

Although the biosphere provides environmental conditions that support life, these conditions are not the same everywhere on Earth. As a result, the types of life that can survive in a particular place are also not the same. A **biome** is a large geographical region with a particular range of temperature and precipitation levels, and the plants and animals that are adapted to those climate conditions.

info BIT

Depending on the specific factors used, our planet can be divided into as few as six and as many as twelve different biomes.

Biomes Are Open Systems

Biomes function as a **system**, or a set of interconnected parts. The **surroundings** of a system is everything that is outside the system. Any system that exchanges matter and energy with its surroundings is an **open system**. Biomes are open systems because they exchange both matter and energy with their surroundings. A **closed system** does not exchange matter with its surroundings, but does exchange energy. Earth's hydrosphere is an example of a closed system, in which space is the surroundings.

A cell is also an open system, since it exchanges matter and energy with its surroundings. Cells take in nutrients and energy and export wastes to their surroundings, which is the region outside the cell membrane. The cell system does this while maintaining conditions within a range necessary for life. For example, a cell would die if it were to allow too little or too much water to move inside. Biomes are similar to cells in that they also exchange matter and energy with their surroundings (Figure D2.32). Like cells, biomes allow matter to move into and out of their boundaries. This matter comes from other biomes, and may be in the form of organisms that travel from one biome to the next, or chemicals that move through the hydrosphere, lithosphere, or atmosphere.

Like cells, biomes also need energy to survive. Virtually all the energy for a biome is supplied by solar energy, or energy from the Sun. This energy maintains the temperature of the biome, and is also used to provide food for organisms living in the biome. Energy can also leave the biome. Some energy is radiated out into space, and the rest is transferred to the other biomes.

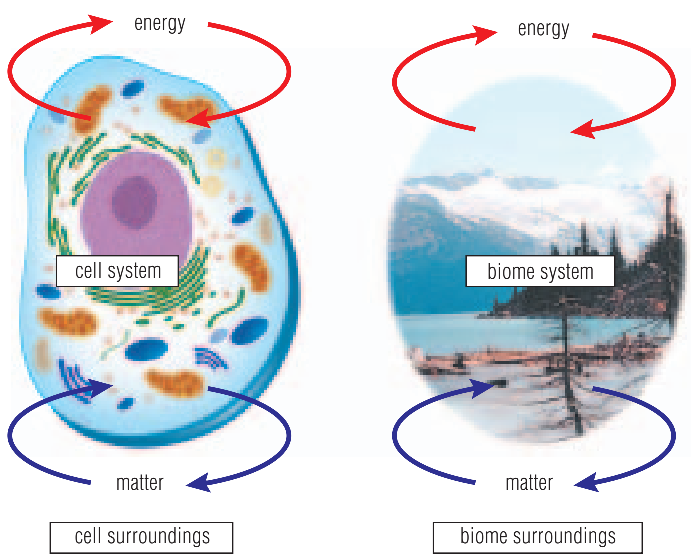


FIGURE D2.32 Cells and biomes are open systems that exchange matter and energy with their surroundings.

Minds On... Open Systems

As a class, choose any two biomes in Figure D2.33 that are located next to one another. For each biome, brainstorm ways in which energy and matter can be moved in and moved out of the biome. Make your suggestions as specific as possible. For example, you might name species of organisms that are found in each or both of the biomes. Keep a list of all the suggestions.

Working in small groups, make a chart or point-form summary that describes how each of the exchanges on the class list might occur. For example, you might suggest that pollen from a plant in one biome is blown into the second biome.

How would your suggestions change if biomes were closed systems? Explain your answer.

Earth's Biomes

Figure D2.33 shows regions of Earth's surface divided into six different biomes. Although biomes have a defined range of temperature and precipitation to which the plants and animals in the biome are adapted, the particular plants and animals found in various regions of these biomes may vary, due to

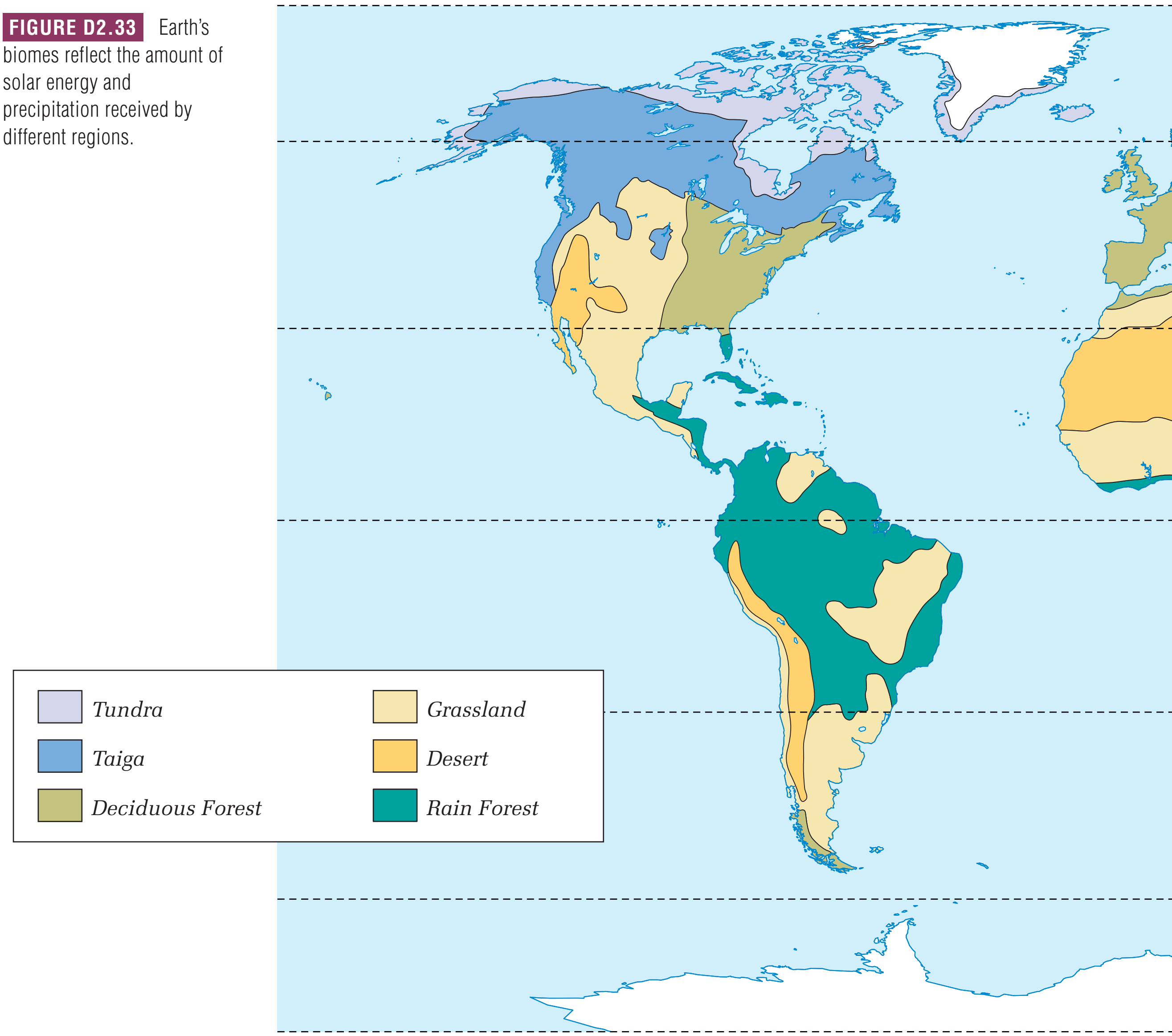
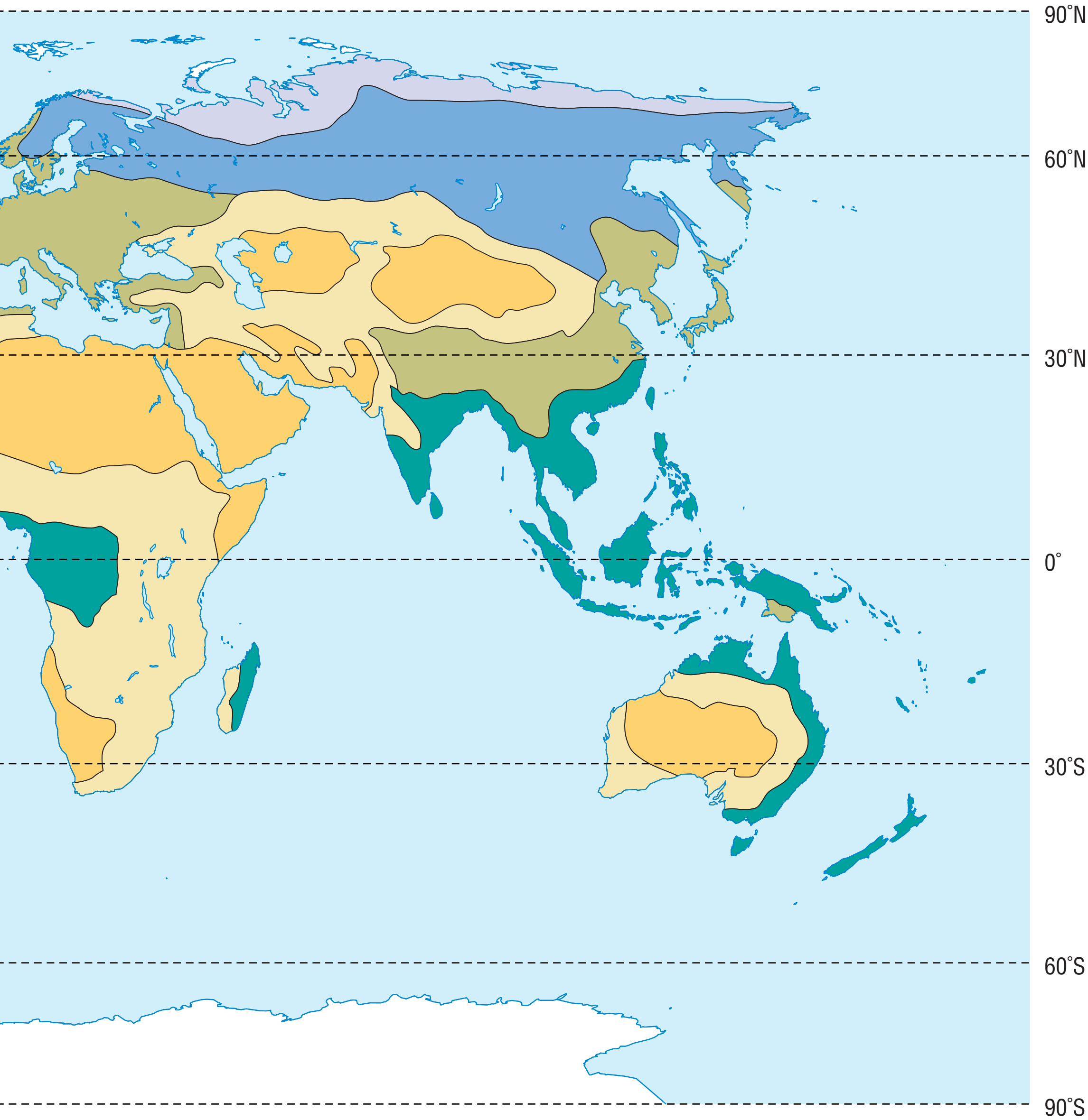


FIGURE D2.33 Earth's biomes reflect the amount of solar energy and precipitation received by different regions.

additional factors such as soil types, topography, and human activity. For example, in the Rocky Mountains, the topography changes dramatically. Here, the valleys and foothills usually are covered with thick coniferous forests, which support animals such as grizzly bears, marmots, and hawks. As the elevation increases, however, the air becomes colder and can hold less moisture, so eventually there is not enough water to support tree growth. Above a certain elevation (the tree line), only low-lying, drought-resistant plants, such as mosses, and small animals, such as mice and other rodents, are found.

Dividing Earth into biomes helps scientists to study and understand the interactions between the living and non-living components of each biome, and how the biomes interact with one another. Biome divisions also make it easier for scientists to predict how different groups of organisms may be affected by changes that may occur in a region, such as a decrease in precipitation. You may come across maps that show different biomes than in Figure D2.33. This is because scientists sometimes classify biomes in ways other than in this textbook, depending on the nature of their studies.



Tundra

Tundra can be found in the arctic regions of North America and Eurasia. Most tundra is found around the Arctic Circle, which is at latitude 66.33° N. At these latitudes, the number of hours of daylight varies greatly over the year. At the summer solstice, daylight lasts for 24 hours, but at the winter solstice, there is no daylight at all. Tundra biomes therefore receive very little solar energy during the winter months. The annual amount of insolation in tundra biomes is the lowest of all the biomes, and ice and snow cover most of the tundra year-round. As a result, lower layers of the ground are permanently frozen (permafrost). The low insolation and high albedo from year-round ice- and snow-cover maintain very cold temperatures in tundra biomes.

Tundra also has very little precipitation (Figure D2.34). As a result, relatively few plants and animals inhabit the tundra (Table D2.2). The plants and animals that live in the tundra are adapted to the conditions of that environment, including the climate. Plants have a very short life cycle so they may complete reproduction during the brief summer season. Many are very small and lie close to the ground, to limit their exposure to the cold and the high winds that are common in the tundra. Since there are few plants, the animals of the tundra mostly feed on fish and other animals. Small animals protect themselves from the cold by burrowing underground, while larger animals often have thick coats and squat bodies to reduce loss of thermal energy.

TABLE D2.2 Characteristics of Tundra Biomes

Climate
• precipitation > 20 cm/y; mostly as snow • average annual temp. –15°C to 5°C • very short summer season (20–30 days)
Plants
• lichens, mosses, sedges • few dwarf woody shrubs
Animals
• ptarmigan, migratory birds in summer • arctic fox, snowshoe hare, lemming • caribou, reindeer, musk ox • wolves, polar bear

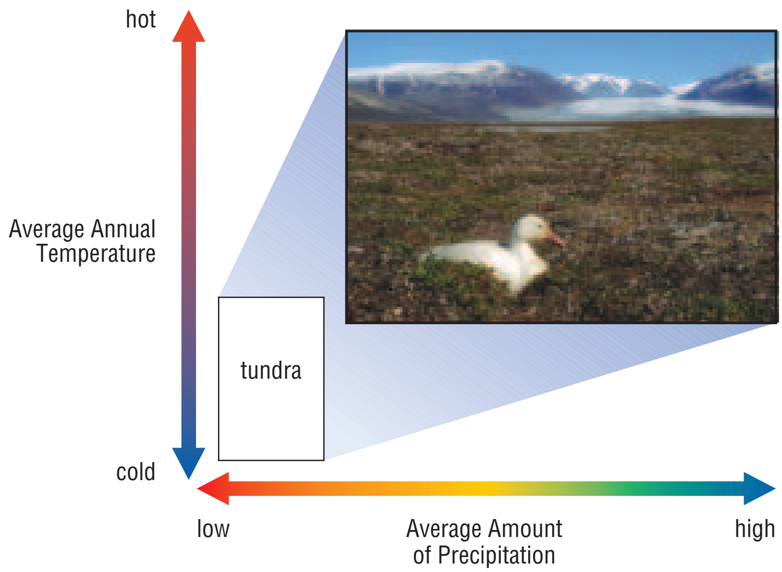


FIGURE D2.34 Tundra biomes are very cold and dry, and have extremely short summer and long winter seasons.

Taiga

Taiga is found in a broad belt around Earth, just south of the region of tundra biomes. Taiga is dominated by evergreen conifer trees, such as fir, pine, and spruce. Taiga may also be called boreal forest. There are few shrubs or bushes in taiga, because the thick conifer branches tend to block out most of the light. A few lichens, mosses, and ferns may be found in more open areas, however. Taiga has more precipitation and higher temperatures on average than tundra (Figure D2.35). Because of the insolation at these latitudes of Earth, taiga also has a longer growing season than tundra. As a result, more plants can survive in taiga than in tundra, which in turn support more animals (Table D2.3). Taiga covers much of Alberta, and is of great economic value as a source of forest products, such as lumber.

TABLE D2.3 Characteristics of Taiga Biomes

Climate
• precipitation 40 to 100 cm/y; much as snow • average annual temp. 4°C to 14°C • cool summers, cold winters
Plants
• cone-bearing evergreens • few lichens and mosses
Animals
• woodpeckers, chickadees, grosbeaks, hawks, eagles • rodents, rabbits, squirrels • moose, bear, lynx, fox, wolves

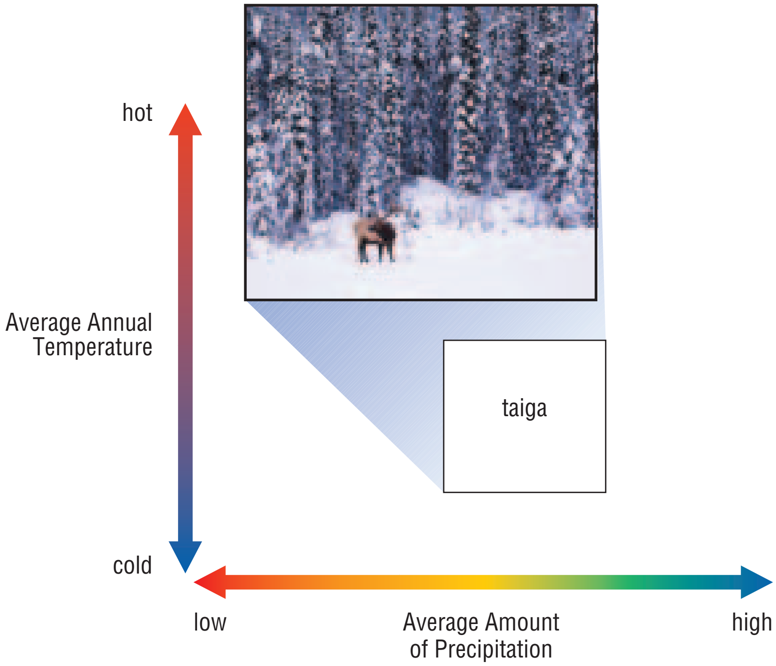


FIGURE D2.35 Taiga biomes have cool summers, and long, cold winter seasons with much snow. There is little water available for plants during the winter due to freezing.

The leaves of evergreen conifers, such as fir, cedar, and spruce, are needle-shaped and contain large amounts of resin, an adaptation which makes them resistant to the freezing and drought conditions of the long winter season. Evergreen conifers therefore can undergo photosynthesis year-round. Animals found in taiga biomes also have adaptations to increase their chances of surviving the long winter season, when food can be scarce and the weather cold. Most are relatively inactive during the winter, either hibernating or remaining in burrows. The coat colour of some animals, such as the arctic fox, changes from brown in the summer to white in the winter, providing year-round camouflage to help them to hunt or to avoid hunters. Birds of the taiga usually migrate in the fall, avoiding most of the winter weather.

Deciduous Forest

Deciduous forest biomes are distinguished by trees that lose their leaves each fall, such as oaks, maples, and ash. Deciduous forests are found in parts of North and South America, Europe, Asia, Japan, and Australia, predominantly between latitudes 30° N and 60° N. This type of biome has a more moderate climate (Figure D2.36) and a longer growing season than taiga. The variation in the amount of insolation during the year at these latitudes results in very distinct winter and summer seasons. Deciduous trees allow light to penetrate to the forest floor, so shrubs, mosses, lichens, and ferns are also common. This rich mixture of plants provides food and habitat for many kinds of animals (Table D2.4).

TABLE D2.4 Characteristics of Deciduous Forest Biomes

Climate
• precipitation 75 to 150 cm/y • average annual temp. 14°C to 27°C • well-defined summer and winter seasons
Plants
• broad-leaved deciduous trees • mosses, lichens, ferns
Animals
• insects and birds; ground-dwelling birds (turkey, pheasant) • squirrels, rabbits, skunk, chipmunks • white-tailed deer, black bear, timber wolf, red fox

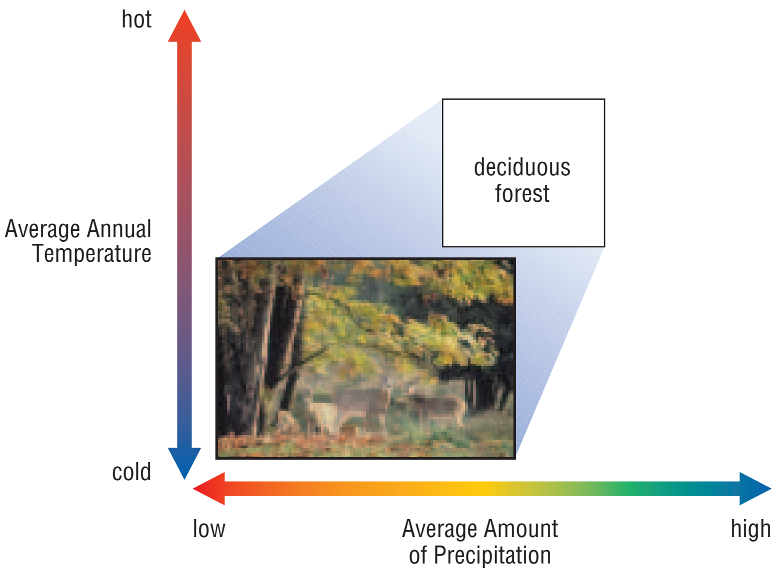


FIGURE D2.36 Deciduous forest biomes have a moderate climate with distinct winter and summer seasons. Water is limited during winter, since most is frozen.

The annual average temperature of deciduous forests is higher than taiga, which enables broad-leaved trees to survive. Broad leaves, such as those of the maple, are more efficient at photosynthesis than needle-shaped leaves, but also freeze easily and lose high amounts of water through transpiration. By losing their leaves each fall, deciduous trees are protected from freezing and require little water during the winter season. Many animals in deciduous forests remain active year-round, but most time their reproduction to coincide with the spring or summer seasons, when food is plentiful and temperatures are milder.

Grassland

Grassland biomes are grassy regions with few or no trees. Trees require far more water than grasses. This biome type occurs in any region where precipitation is at least 20 cm per year, and yet still too low to support the growth of trees (Figure D2.37). The average annual temperature of grassland biomes ranges from 4°C to 30°C. Grasslands occur on all continents, and may be known by different names, depending on other distinguishing factors.

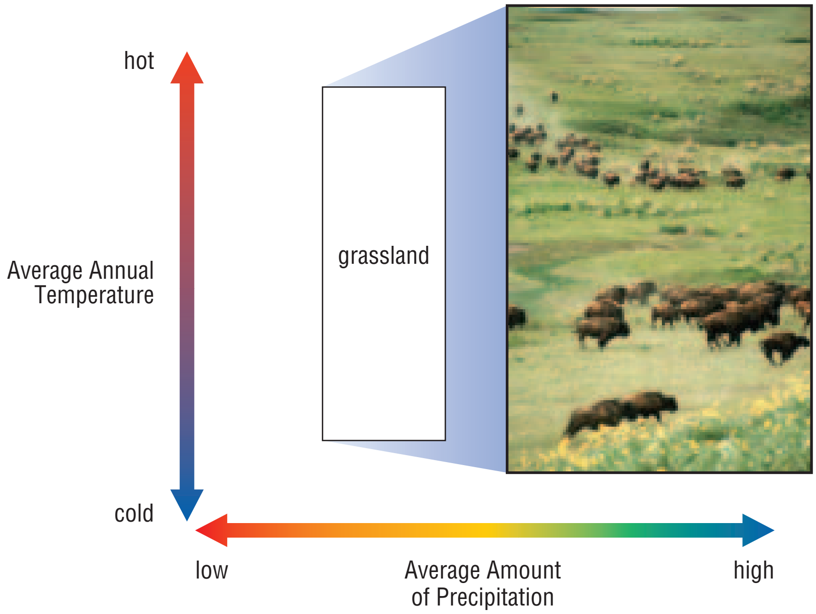


FIGURE D2.37 All grasslands receive little precipitation throughout the year, and also have periods of drought, either in winter (prairies) or during the dry season (savannas). Savanna grasslands have warm temperatures, whereas prairie grasslands have moderate temperatures.

TABLE D2.5 Characteristics of Grassland Biomes

Grassland Type	Climate	Plants	Animals
prairie	• precipitation 25 to 57 cm/y • average annual temp. 4°C to 18°C • winter and summer seasons	• grasses • some forbs	• hawks, snakes • mice, gophers, rabbits • buffalo, deer, elk, antelope • coyotes, badgers, kit foxes
savanna	• ppt. 25 to 57 cm/y • average annual temp. 18°C to 30°C • wet season and dry season	• grasses • scattered trees	• insects, birds, reptiles • elephants, giraffe, antelopes, zebras, wildebeest, rhinoceros • cheetah, lion, hyena

In North America, grasslands are often referred to as **prairie**. Natural prairies are dominated by tallgrass or shortgrass plants, and may also contain drought-tolerant flowering plants known as forbs. Prairie regions have warm summers and cold winters. Most of the natural prairie of North America has disappeared and been replaced by agricultural land. In Alberta, for example, most crops are grown in regions that were once natural prairie. **Savannas** are grasslands found in regions such as Africa, Central America, and Australia. The temperature in these regions does not vary much with the seasons, but there are pronounced seasonal differences in precipitation (a wet season and a dry season). As a result, savannas usually have scattered, drought-tolerant trees as well as grasses.

Although the particular species found in grassland regions can be very different (Table D2.5), they all are adapted to dry climate conditions. Grasses have extensive root systems that allow quick recovery from drought, cold, or grazing. Most die off each year and start from seed when weather conditions are suitable, thus avoiding the more difficult weather of the winter season of prairie grasslands or the dry season of savannas. Most grassland animals are grazers. Large grazers must be able to travel great distances, in order to find sufficient food. Grasslands also support small burrowing animals, which construct underground burrows to protect themselves from harsh weather and predators. Humans also rely on grasslands for much of their food, either directly as grasses (e.g., wheat and corn) or as products of grazing animals (e.g., cattle and sheep). Alberta's agricultural industry depends on plants and animals that are adapted to a grassland biome.

Rain Forest

Rain forests contain the richest diversity of plants and animals of all the biomes. Rain forests have over 200 cm of rain every year and are always warm, conditions that allow plants to grow year-round (Figure D2.38). The dominant plants of rain forests are broad-leaved trees, which may be either evergreen or deciduous, depending on the location of the rain forest. Many other plant species grow under and on these trees, such as vines that travel up entire tree trunks, or rootless air plants, which take up moisture through their leaves from the humid air. This rich plant life supports an equally rich population of animals (Table D2.6).

TABLE D2.6 Characteristics of Rain Forest Biomes

Climate
• precipitation > 200 cm/y • average annual temp. 25°C to 30°C • may have short dry season
Plants
• broad-leaved trees, evergreen and deciduous • vines and shrubs • air plants
Animals
• hummingbirds, parakeets, parrots, toucans • snakes, lizards, frogs • paca, agouti, peccary, armadillo, coatimundi • monkeys, gorillas, jaguars, tigers

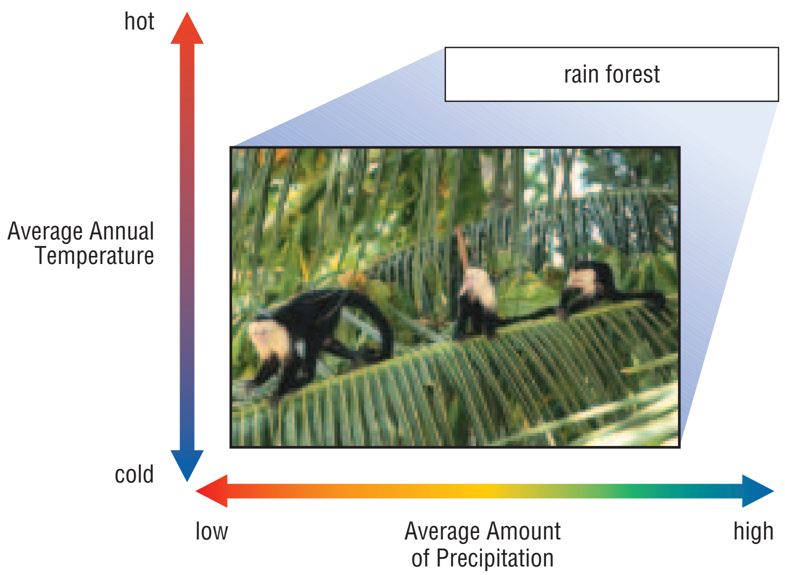


FIGURE D2.38 Rain forests are usually warm and moist throughout the year, although some may be relatively dry for short periods.

Since rain forests have so many plants in any one area, the amount of shade varies at different levels of the forest. Many plants are adapted to maximize their exposure to sunlight, which may include broad leaves, great height, or the ability to climb (e.g., vines). Others are adapted to life in relative shade, and rely on larger plants to produce these conditions. Animals in the rain forest are active year-round, and have a wide variety of adaptations. Each species is specialized for life in a particular part of the rain forest, such as on the ground, at mid-tree level, or in the treetops.

Desert

A desert biome always has less than 25 cm of rainfall per year (Figure D2.39), and so has relatively little plant life. Some deserts, such as the Sahara, have as little as 2 cm of rain per year. Deserts receive high levels of insolation, and so are quite hot during the day. Since deserts lack water and plants, there is not enough material with sufficient heat capacity to retain thermal energy, so deserts are quite cold at night. The most recognizable plants of the desert are the succulents, such as cacti, which store water in fleshy stems and leaves. Non-succulent plants are also found, such as drought-tolerant trees (Table D2.7). Deserts support a number of unique animal species adapted to the hot, dry climate, such as camels and running birds. Animals of the desert require relatively little water, and are often active only at night.

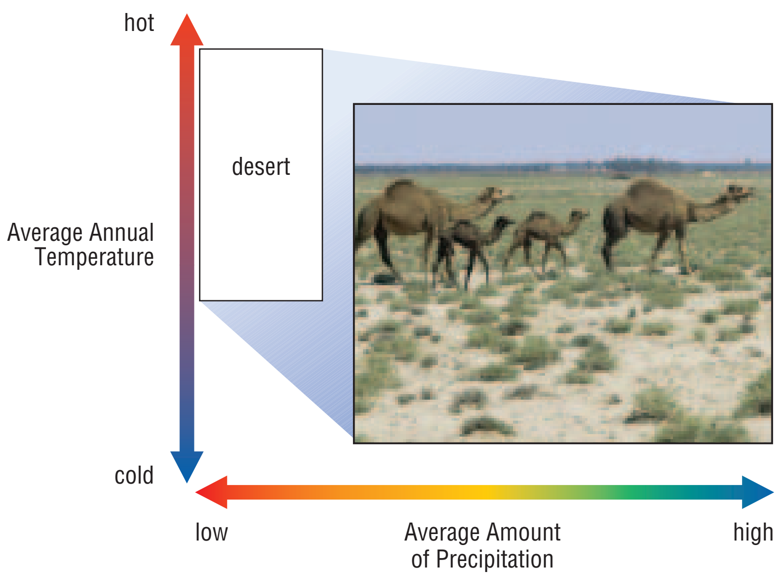


FIGURE D2.39 Desert biomes are the driest biomes. Temperature varies considerably during the day in deserts, with very hot days and cold nights.

TABLE D2.7 Characteristics of Desert Biomes

Climate
• precipitation < 25 cm/y • average annual temp. 12°C to 27°C • days hot, nights cold
Plants
• succulent plants (cacti) • non-succulent, drought-tolerant plants (sagebrush, mesquite tree)
Animals
• millipedes, centipedes, scorpions, spiders, lizards, snakes • running birds (ostrich, roadrunner) • antelope, goats, sheep, camels • bats, rodents, rabbits • coyote, kit fox, dingo dog

Biomes and Climate

The climate of each of Earth's biomes plays a major role in determining the plants and animals that can survive in a region, and the types of adaptations they need. Figure D2.40 summarizes the relationship between the six biomes and average temperature and precipitation. On the horizontal axis, precipitation levels increase from left to right. On the vertical axis, temperature levels increase from bottom to top. Each biome is placed on the graph according to its average yearly precipitation and temperature range. Note that this graph shows very general trends only. Since climate conditions change gradually, there is no distinct line between one biome and another, and many regions on Earth have characteristics intermediate between two biomes.

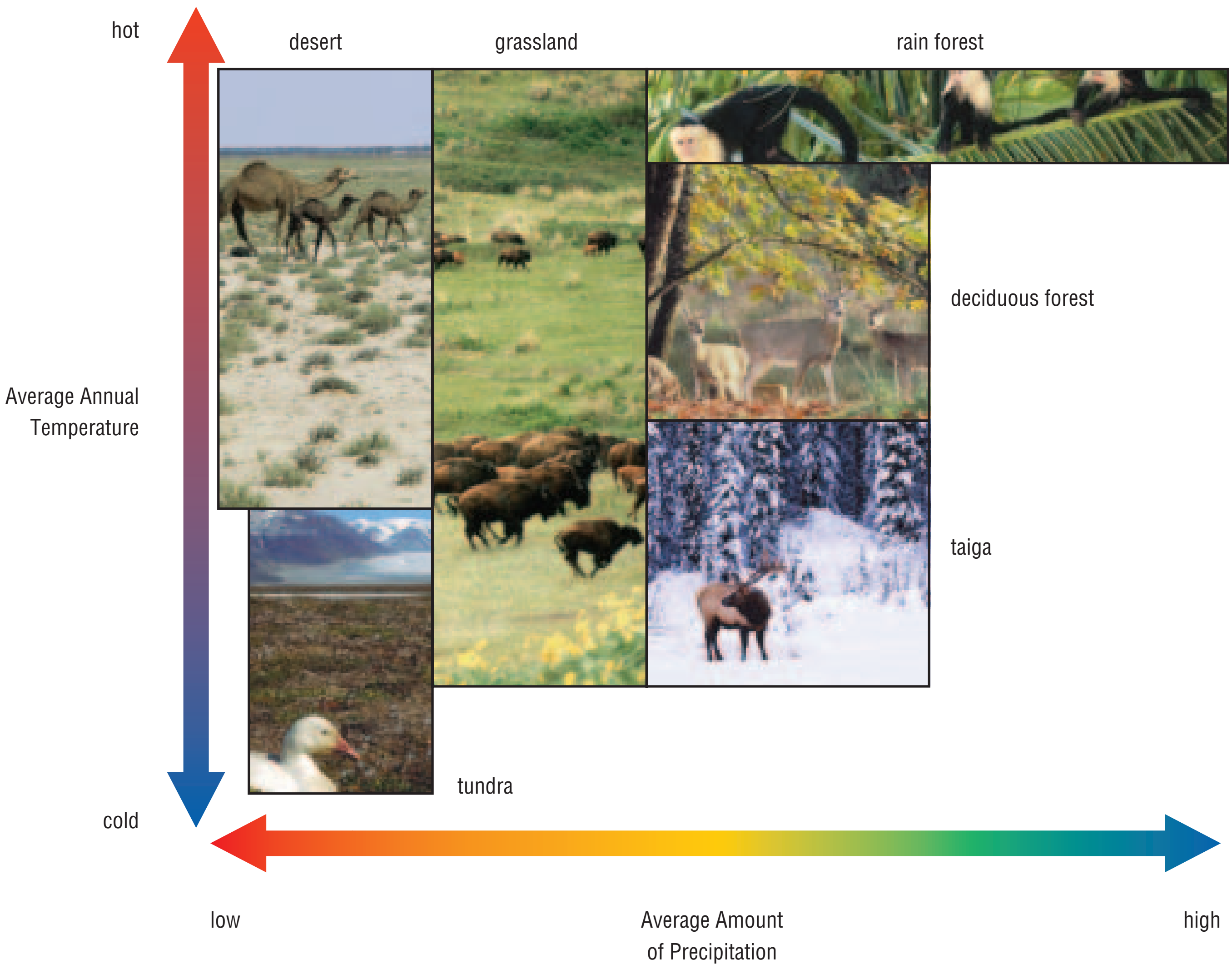


FIGURE D2.40 The characteristics of each of Earth's biomes are related to the climate conditions.

Activity D15

Problem-Solving Investigation

Student Reference 7

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Planning for Climate

Begin your search at www.pearsoned.ca/school/science10

Recognize a Need

A research group is studying the living organisms found at various sites in Alberta (Figure D2.41). This year, one group will be at Wood Buffalo National Park (near Fort Smith weather station) and a second group at Dinosaur Provincial Park (near Brooks weather station). The researchers will live in the park for one year, and most of their work will be conducted outdoors. They will spend some of their time in remote regions of the park.

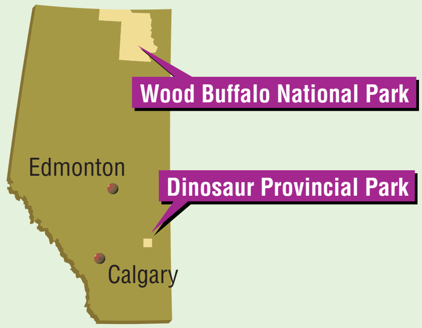


FIGURE D2.41 These two parks are in different biomes.

The Problem

Before the project can move ahead, all the needed supplies for each park must be identified. Since there is a limited amount of funding, only the minimum number of necessary items can be included. Research the climate conditions and identify the biome of each park. Based on this information, plan out how to meet the basic needs for each month of the year for each of the two research teams.

Criteria for Success

To be successful, your two plans must meet the following criteria:

- Identify the biome in which each park is located.
- Describe the climate conditions in each park for each month, including the average temperature, average amount of rain, and average amount of snow.
- List specific supplies that will be needed to work outdoors in each park for 12 months. Assume that researchers will need to stay at least 2 nights in the shelter in a remote area each month.
- Communicate your choices, and clearly and accurately describe the connection to climate conditions.

Brainstorm Ideas

1. Work with a partner or in a small group. Brainstorm ideas that would fit the criteria. All ideas should be considered.
2. Incorporate the best ideas into one list of potentially useful supplies for each park.

Design a Presentation

3. Decide what additional information you need to decide on the most appropriate items to include on your supply list for each park. Conduct further research if necessary.
4. When all research is complete, design an effective presentation of your supply list that will clearly show how differences in the climate of the two parks impacted the supplies needed by the researchers. Remember to keep track of your decisions as you work, since they will form part of your presentation. Your presentation may be done on paper or with the aid of a computer.
5. Create your presentation.

Evaluate and Communicate

1. What are the main differences in climate between the two sites?
2. How was your list of supplies affected by these climate conditions?
3. Two important factors in climate are the average temperature range and the average amount of precipitation. Which of these do you think is most important to the living things in each park? Why?
4. Share and compare your presentation with others in the class.

*re*SEARCH

Determine the biome of your community. Find another city in the world in the same type of biome, and compare the plants and animals that are found in the two areas. Begin your search at

www.pearsoned.ca/school/science10

Canada's Biomes

Canada has four biomes: tundra, taiga, grassland, and deciduous forest (Figure D2.42). Most of Canada is a taiga biome, but grassland and deciduous forest regions are very important. Most of our agricultural crops are grown in these regions, since they support the growth of the plants and animals on which we rely.

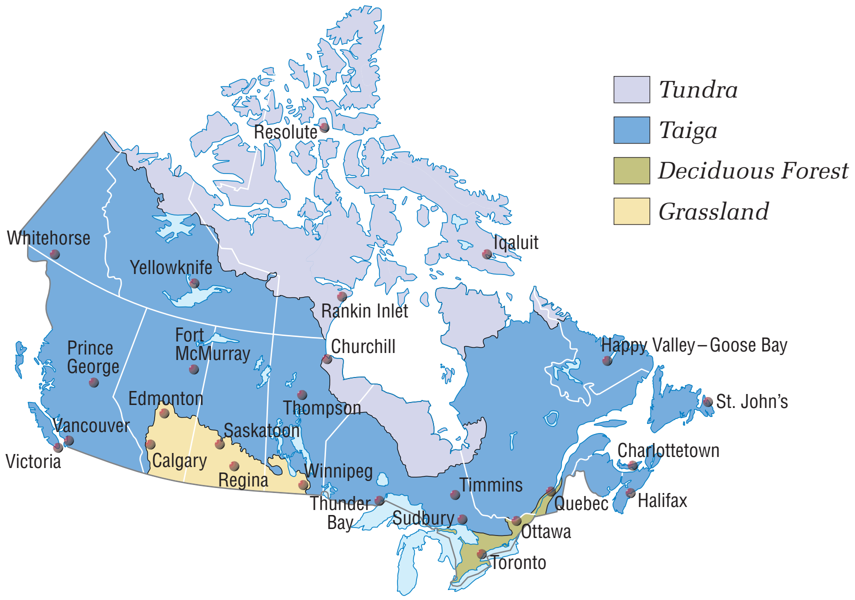


FIGURE D2.42 Canada can be divided into four biomes; two of these biomes are found in Alberta.

D2.4 Check and Reflect

Knowledge

1. What is a biome?
2. Explain why a biome is an open system.
3. Describe the surroundings of a biome.
4. Explain how dividing Earth into biomes helps scientists to study and understand Earth.
5. Describe the characteristics of the biome in which you live.
6. Name two biomes that have very low average annual precipitation.
7. Compare and contrast the plants and animals that would be found in a grassland biome in Alberta, Canada to those found in a grassland biome in the country of Sudan, in Africa.
8. Identify the biome in which organisms with the following adaptations are most likely to be found:
   a) large, leafy plants that do not lose their leaves
   b) animals that change coat colour from white to brown each year
   c) animals that time reproduction to have young only in spring and summer
   d) plants that can store water
   e) animals that feed mostly on fish and other animals

Applications

9. In a paragraph, compare a biome to a cell.
10. Using the information in Figure D2.42, create a map of the biomes of Alberta. Use print and electronic resources to identify at least three species of plants and three species of animals that are found in each biome.

Extension

11. In 2001 and 2002, Alberta farmers experienced droughts so severe that some were unable to feed their livestock or harvest any crops. Wild species were also affected. Which of Alberta's biomes do you think was most impacted by this drought? Explain your choice.

D 2.5 Analyzing Energy Flow in Global Systems

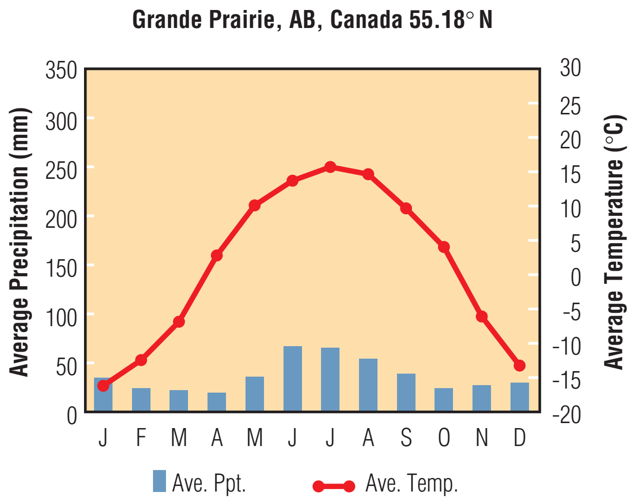
In previous sections, you learned that the climate of any area on Earth is determined by many interacting factors. The insolation of an area is determined by that area's latitude, the number of hours of daylight, and the time of year. The albedo, cloud and dust cover, and the natural greenhouse effect interact with insolation to give each area a particular net radiation budget. Convection currents and the Coriolis effect cause predictable global wind patterns in the atmosphere, which transfer thermal energy between areas at or near the equator and those at or near the poles. The world's ocean currents moderate air temperature due to the large specific heat capacity of water. The hydrologic cycle also contributes to thermal energy transfer, through the release and absorption of thermal energy that occurs when water warms, cools, and changes phase.

To fully understand climate, all these interactions must be considered. One of the simplest tools for analyzing the relative impact of these factors on an area is a climatograph. A **climatograph** is a summary of the average temperature and precipitation for each month of the year for a given location, presented as a graph. Figure D2.44 shows a climatograph for Grande Prairie, Alberta, and for Manokwari, Indonesia. Grande Prairie is in a taiga biome, whereas Manokwari is in a rain forest biome. The vertical axis on the left of a climatograph shows the average precipitation (ave. ppt.) in millimetres. The vertical axis on the right shows the average temperature (ave. temp.) in degrees Celsius, and the months of the year are shown on the horizontal axis. The values for average precipitation are always plotted as a bar graph, and values for average temperature are plotted as a line graph.

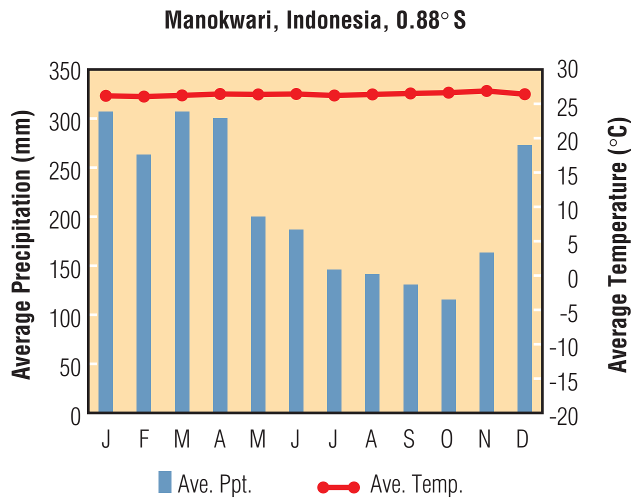
FIGURE D2.43 Biomes result from the patterns of thermal energy transfer on Earth.

infoBIT

The coldest temperature ever recorded in Canada was −63°C, in Snag, Yukon, on February 3, 1947. The hottest temperature was 45°C, in Midale and Yellow Grass, Saskatchewan, on July 5, 1937.



(a) Climatograph of Grande Prairie, Alberta



(b) Climatograph of Manokwari, Indonesia

FIGURE D2.44 A climatograph provides a visual summary of climate conditions of an area.

To compare the climates of different areas, the scale of the vertical axes on each climatograph must be the same. In Figure D2.44, the precipitation scales of both climatographs reflect the range of the data for Manokwari, since this area has the higher precipitation levels. The temperature scales reflect the maximum temperature in Manokwari, and the minimum temperature in Grande Prairie. If you compare the two climatographs, you can see that the monthly average temperature of Grande Prairie changes significantly with the seasons, but Manokwari experiences little variation in monthly average temperature from month to month. Also, precipitation levels in Grand Prairie are relatively low year-round, and are highest from May to September. Precipitation levels in Manokwari are high year-round, and are highest from December to April.

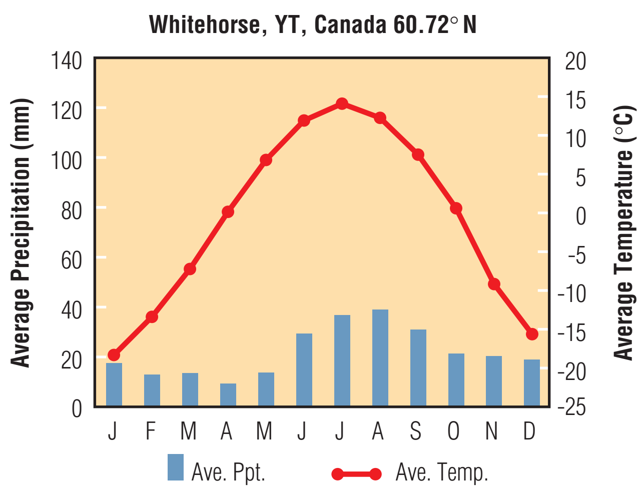
Climatographs can also help to identify the factors that determine the climate of an area. In this unit, you have learned how the following factors can affect climate:

- Insolation, which is mostly related to the latitude of a region; other factors can cause daily changes in insolation, including cloud cover, albedo, and the level of atmospheric dust.
- The pattern of global winds that prevail over a region
- The pattern of the warm and cold currents in Earth's oceans, and the effect of differences in specific heat capacity of water and of air on cooling and heating of a region

Of all these factors, insolation has the strongest effect on climate. The differences between the climates of Grande Prairie and Manokwari are primarily due to the insolation at their different latitudes. However, the other factors can also significantly affect climate in some regions. For example, look at the climatographs shown in Figure D2.45, for Whitehorse, Yukon, and Lerwick, a city in the Shetland Islands of the United Kingdom.

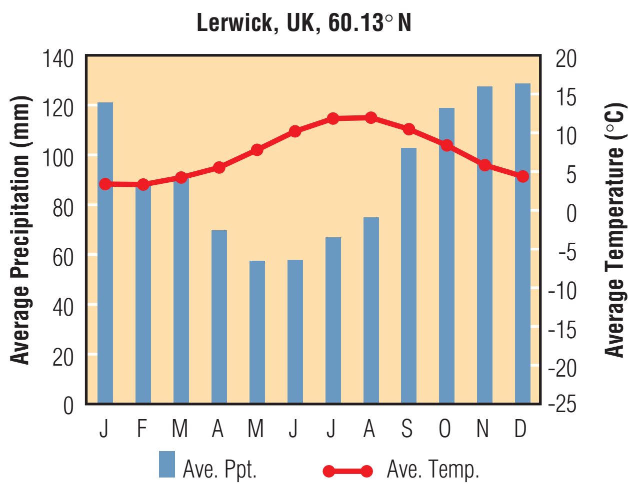
These two cities are at almost the same latitude, and so receive similar insolation. However, the climatographs clearly show that the climates of these two regions are quite different. Lerwick is warmer and wetter than

FIGURE D2.45 Although they are at similar latitudes, the climates of Whitehorse and Lerwick are very different.



Source: Environment Canada

(a) Climatograph of Whitehorse, Yukon



Source: World Climate (www.worldclimate.com)

(b) Climatograph of Lerwick, United Kingdom

Whitehorse year-round. The prevailing winds for both regions are the polar easterlies (see Figure D2.22). However, if you look at the pattern of Earth's ocean currents in Figure D2.23, you will see that the Shetland Islands are located in the path of a warm ocean current moving up from the Atlantic Ocean. This warm ocean water warms the air temperature throughout the year and increases the precipitation. Whitehorse, in contrast, is inland, and so its climate is affected mostly by the amount of insolation at that latitude. These two cities are therefore in different biomes. Lerwick is in a deciduous forest biome, whereas Whitehorse is in a taiga biome.

You could also predict the biomes of these two regions by examining their climatographs. The evergreen tree species that survive in boreal forest biomes have adaptations such as needle-like leaves that allow them to survive in a relatively dry, cold climate. Deciduous trees require higher levels of precipitation and higher temperatures than evergreens.

reSEARCH

Find out how climates are influenced by local factors. What factors influence the climate in your community? Begin your search at www.pearsoned.ca/school/science10

Activity D16

QuickLab

Constructing a Climatograph

Purpose

To construct and interpret a climatograph

Materials and Equipment

graph paper or spreadsheet software

Procedure

1. Copy the data in the table below into a new spreadsheet file or graph it on a clean sheet of graph paper.
2. Begin your climatograph by marking the months of the year along the horizontal axis of the graph.
3. Determine the range of the temperature data for the year. Construct and label a vertical axis on the right side of your graph according to this temperature range.
4. Plot the average temperature for each month as a line graph.
5. Determine the range of the average precipitation data over the year. Construct and label a vertical axis on the left side of your graph according to this precipitation range.
6. Plot the average precipitation data for each month as a bar graph.
7. Write a legend and title for the climatograph. The title should include the location and the latitude.

Questions

1. From the patterns in your climatograph, describe how average temperature varies during the year in Jasper.

2. From the patterns in your climatograph, describe how average precipitation varies during the year in Jasper.

3. Identify the biome of Jasper.

Average Temperature and Precipitation in Jasper, Alberta (latitude 53° N)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average Temperature (°C)	–10.7	–5.9	–1.6	3.8	8.1	12.8	15.1	14.6	9.8	4.7	–4.0	–9.7
Average Precipitation (mm)	31.1	17.4	15.7	21.2	28.6	49.9	56.2	50.6	37.0	30.9	28.2	26.8

Source: Environment Canada

Activity D17

Inquiry Lab

Student Reference 7

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Using Climatographs to Compare Biomes

Begin your search at
www.pearsoned.ca/school/science10

The Question

What does the information in a climatograph tell us about the biome of an area?

The Hypothesis

A climatograph summarizes the climate conditions of an area, which determine the type of vegetation.

Materials and Equipment

Internet access (optional)

atlas

graph paper or spreadsheet software

Average Climate Conditions

Month	Victoria, BC		Edmonton, AB	
	Average Temp. (°C)	Average Ppt. (mm)	Average Temp. (°C)	Average Ppt. (mm)
Jan	3.4	141.1	–12.5	23.3
Feb	4.8	99.3	–8.9	16.8
Mar	6.1	71.9	–3.6	17.0
Apr	8.4	41.9	4.9	22.1
May	11.4	33.4	11.6	43.5
June	14.3	27.3	15.6	79.9
July	16.2	17.6	17.5	94.3
Aug	16.2	23.7	16.6	67.0
Sept	13.8	36.6	11.1	41.6
Oct	9.7	74.4	5.9	17.3
Nov	6.0	139.2	0.6	16.1
Dec	3.8	151.6	–8.4	22.2

Source: Environment Canada

Procedure

1. Using data from the given table, create a climatograph for these two cities in Canada. Alternatively, find and use climate data from the Internet, for two cities that interest you.

2. Complete the following steps for the climate data for each city:
   a) Write the names of the months along the horizontal axis.
   b) Determine the range of temperature in the data. Label the vertical axis on the right side to fit this range.
   c) Plot the average temperature for each month as a line graph.
   d) Determine the range of average precipitation, and label the vertical axis on the left side to fit this range.
   e) Plot the average precipitation as a bar chart.
   f) Prepare a legend and a title for your climatographs. Your title should include the name of the location, the latitude of the location, and the type of biome being represented. Carry out any research necessary to obtain all the information you need.

Analyzing and Interpreting

1. For each city, use your climatograph to summarize the type of climate found in that area. Identify the biome of each city.

2. Suggest reasons to explain the differences in the climates of the two cities you investigated. Justify your answer with facts.

Forming Conclusions

3. Summarize the general trends found in each of your climatographs and describe the characteristics of the biome of each city.

D2.5 Check and Reflect

Knowledge

1. In point form, list the factors that play a role in determining the climate of an area.
2. What is a climatograph?
3. What two main factors are used when describing a region in a climatograph?
4. Explain why a coastal region would have a significantly different climate than would an inland region at the same latitude.
5. Construct a climatograph for Medicine Hat, Alberta, using the information in the table below. Medicine Hat is at latitude 50.05° N.

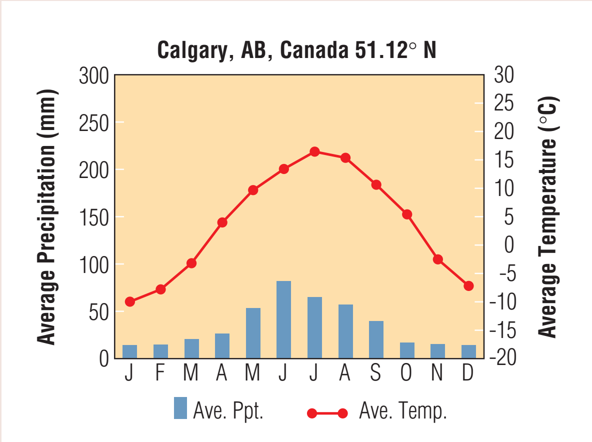
Average Climate Conditions of Medicine Hat, AB

Month	Average Precipitation (mm)	Average Temperature (°C)
Jan	16.8	−11.0
Feb	14.6	−8.8
Mar	17.4	−2.1
Apr	21.9	6.7
May	41.2	12.6
June	59.7	16.9
July	40.7	20.4
Aug	35.3	19.1
Sept	32.1	13.3
Oct	16.5	7.4
Nov	16.0	−1.4
Dec	15.7	−7.3

Source: World Climate (www.worldclimate.com)

Applications

6. Two regions on Earth have the same latitude, but different climates. Suggest two factors that might cause this difference in climate.
7. Why do some regions on Earth have different amounts of insolation?
8. If a region experienced one year in which the weather was much colder than on average, would the climatograph of that region change? Explain your answer.
9. From the climatograph below, describe the relationship between precipitation and temperature in a series of statements.



Source: Environment Canada

Extensions

10. Calgary is in a grassland biome. Relate the information in the climatograph in question 9 above to the type of vegetation that occurs in this biome. For example, a desert biome could be described as an area of high temperature and low precipitation.
11. Find the climate data for another city in the world at the same latitude as your city or town. Construct climatographs of the two areas, then compare and contrast the two climates.

Section Review

Knowledge

1. Identify the two main factors that determine the amount of solar energy a point on Earth will receive.
2. Explain why the albedo of snow is different from the albedo of a forest.
3. Write the word equation for Earth's net radiation budget.
4. Where on our planet is most of the infrared radiation absorbed?
5. Outline how the natural greenhouse effect influences the climate of Earth.
6. The average albedo for Earth is 0.3. What does this value represent?
7. Identify and describe the process that transfers thermal energy from the lithosphere to the atmosphere.
8. Describe the movement of air in relation to atmospheric pressure.
9. Describe how the Coriolis effect influences global wind patterns.
10. In what direction is thermal energy transferred through the hydrosphere?
11. Using an example, explain the hydrologic cycle. Use a diagram in your explanation.
12. What is transferred by the hydrologic cycle, other than water?
13. Define heat of vaporization.
14. Draw a graph of the temperature changes of water as it changes phase from solid to liquid to water vapour. Describe the effects of the heat of vaporization and the heat of fusion on the shape of the curve.
15. Identify three factors that contribute to Earth's climate.
16. Describe two ways in which thermal energy is moved through the biosphere.
17. State the biomes that are found in Canada.
18. Why do grassland biomes have few or no trees?
19. Give two examples of adaptations, one for a plant and one for an animal, that would help the organism to survive in a tundra biome.
20. Which biome supports the highest number of species in the greatest abundance? Why?
21. Sketch and label the key components of a climatograph.
22. State the main factor that determines Earth's biomes. Justify your answer.

Applications

23. Explain why the polar regions of Earth have less insolation than the equator. Use a diagram in your answer.
24. Explain why life on Earth depends on the absorption of infrared radiation by the troposphere.
25. How does the presence of naturally occurring greenhouse gases affect human life? Explain your answer.
26. Describe the process of convection, referring to the motion of particles in your answer.
27. Why does warm air rise?
28. Explain why the temperature of water remains constant when it changes from solid to liquid phase, even though thermal energy is being added.
29. Calculate the final temperature when 100 J of thermal energy is added to 15.0 g of copper at 20.0°C. The theoretical specific heat capacity of copper is 0.385 J/g·°C.
30. Calculate the quantity of thermal energy that is absorbed when the temperature of 12.5 g of nickel increases by 2.5°C. The theoretical specific heat capacity of nickel is 0.444 J/g·°C.
31. The temperature of a mass of tin increases from 24.0°C to 34.0°C when 250 J of thermal energy are added. Calculate the mass of the tin. The theoretical specific heat capacity of tin is 0.228 J/g·°C.
32. Calculate the amount of thermal energy that is released when a 20.0-g mass of zinc at 30°C is cooled to 0.0°C. The theoretical specific heat capacity of zinc is 0.388 J/g·°C.

Section Review

33. A researcher observes that 7.50 mol of water at 100.0°C is vaporized completely when 305 kJ of thermal energy is added. Using this data, determine the experimental heat of vaporization of water to the appropriate number of significant digits.

34. Calculate the amount of thermal energy needed to change 25.0 mol of water at 100.0°C from liquid to vapour phase, without any change in temperature. The theoretical heat of vaporization of water is 40.65 kJ/mol.

35. How much thermal energy is absorbed when 10.0 g of ice at 0.0°C changes phase to liquid water at 0.0°C? The molar mass, M, of water is 18.02 g/mol and the theoretical heat of fusion, H_{fus}, of water is 6.01 kJ/mol.

36. Saskatoon is located at latitude 52.17° N. The table below presents average climate conditions in Saskatoon.

Average Climate Conditions of Saskatoon, SK

Month	Average Precipitation (mm)	Average Temperature (°C)
Jan	18.2	−17.8
Feb	14.2	−14.4
Mar	16.9	−7.6
Apr	20.1	3.6
May	38.3	11.0
June	62.5	15.7
July	57.4	18.6
Aug	42.8	17.3
Sept	35.0	11.2
Oct	19.4	4.9
Nov	16.5	−5.8
Dec	16.5	−14.2

Source: World Climate (www.worldclimate.com)

a) Draw a climatograph for Saskatoon.

b) Predict the biome in which Saskatoon is located. Give reasons for your prediction.

c) Assume your prediction is correct. What kinds of plants and animals would you expect to find in natural areas around Saskatoon?

Extensions

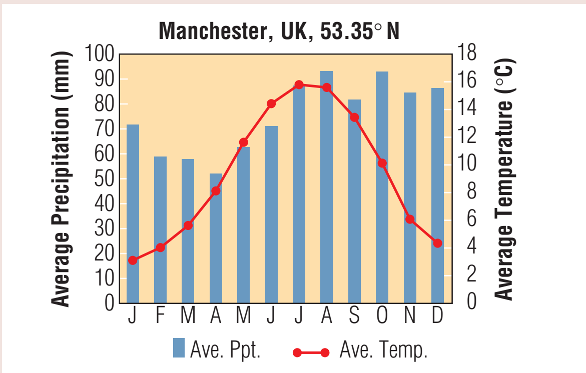
37. Compare the influence on climate of the albedo of a tundra biome and of a deciduous forest biome by answering the following questions:

a) Which biome would have the greatest average albedo over a 12-month period?

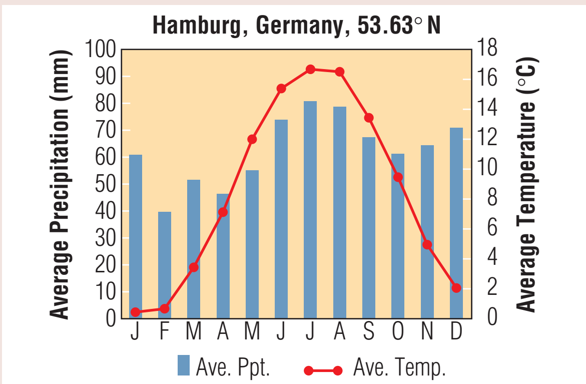
b) Which biome would reflect the most incoming radiation, and which would absorb the most incoming radiation on average over a 12-month period?

c) Would your answers change if you were comparing the albedo of both biomes only in the month of July? Why or why not?

38. The figure below shows climatographs for two cities at similar latitudes: Manchester, United Kingdom, and Hamburg, Germany. Given that Hamburg is further inland than Manchester, deduce reasons for the differences and similarities in the climates of these two cities.



Source: World Climate (www.worldclimate.com)



Source: World Climate (www.worldclimate.com)